GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION
SPONSORED PROJECT INITIATION

Date: 12/5/78

Project Title: Wood Energy Potential in West Virginia

Project No: A-2297

Project Director: ~~J. L.~~ Birchfield ~~Birchfield~~ Carol Atson

Sponsor: Claude Worthington Benedum Foundation

9 mo. Agreement Period: From 10/31/78 Until ~~7/31/79~~ ~~Nov 30, 1979~~ 31 Mar 80

Type Agreement: Ltr. dtd. 10/20/78

Amount: $116,412

Reports Required: Monthly Progress Reports; Final Technical Report

Sponsor Contact Person (s):

Technical Matters

Contractual Matters
(thru OCA)

Mr. Kent J. Frisby
Treasurer
Claude Worthington Benedum Foundation
Benedum - Trees. Bldg.
Pittsburgh, Pa. 15222

Defense Priority Rating:

Assigned to: Technology & Development (School/Laboratory)

COPIES TO:

Project Director
Division Chief (EES)
School/Laboratory Director
Dean/Director–EES
Accounting Office
Procurement Office
Security Coordinator (OCA) ✓
Reports Coordinator (OCA)

Library, Technical Reports Section
EES Information Office
EES Reports & Procedures
Project File (OCA)
Project Code (GTRI)
Other__________

CA–3 (3/76)

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION

Date: April 6, 1981

Project Title: Wood Energy Potential in West Virginia

Project No: A-2297

Project Director: Carol Aton

Sponsor: Claude Worthington Benedum Foundation

Effective Termination Date: 12/31/80

Clearance of Accounting Charges: 12/31/80

Grant/Contract Closeout Actions Remaining:

- X Final Invoice ~~XXXXXXXXXXXXXXXX~~
- _ Final Fiscal Report
- _ Final Report of Inventions
- _ Govt. Property Inventory & Related Certificate
- _ Classified Material Certificate
- _ Other ______________

Assigned to: TAL (School/Laboratory)

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EES Research Public Relations (2)
Project File (OCA)
Other: ______________

A-2297

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

February 5, 1979

Mr. Paul R. Jenkins
Executive Vice President
Claude Worthington Benedum Foundation
Benedum-Tree Building
Pittsburgh, Pennsylvania 15222

Dear Paul:

During January we initiated work on the study entitled "Wood Energy Potential in West Virginia". The following items were accomplished this month:

- We collected available data on the wood supply in West Virginia.
- We visited members of the Governor's staff, the State Forester, the Princeton Forest Service Laboratory, and West Virginia University to discuss the wood supply and general project objectives.
- We performed an initial survey of advanced harvesting techniques that may be utilized to a greater extent in West Virginia.

During the month of February we plan to:

- Complete the wood supply estimate.
- Continue the harvesting and transportation investigation.
- Begin the determination of wood energy actually available.
- Perform an initial survey of potential industrial uses of wood energy.

We will report the wood supply data for each of the eleven West Virginia Planning and Development Regions. This seems to be a more practical subdivision of the state for socio-economic and industrial evaluations than the four Forest Service regions, and should enhance utilization of the results.

A copy of the revised project schedule is enclosed. It is the same accelerated schedule which Jerry Birchfield discussed with you in January, and the investigation is proceeding as planned. The current professional staff members on the project are Carol Aton, Del Lohuis, and John Owen as project manager. We expect to add one full time staff member in February. The enclosed Funding Plan indicates that the budget is within bounds based on our projections.

In summary, the project is off to a fast start, we do not anticipate any budget or schedule problems, and we expect the results to be of significant value to West Virginia both now and in the future.

Sincerely yours,

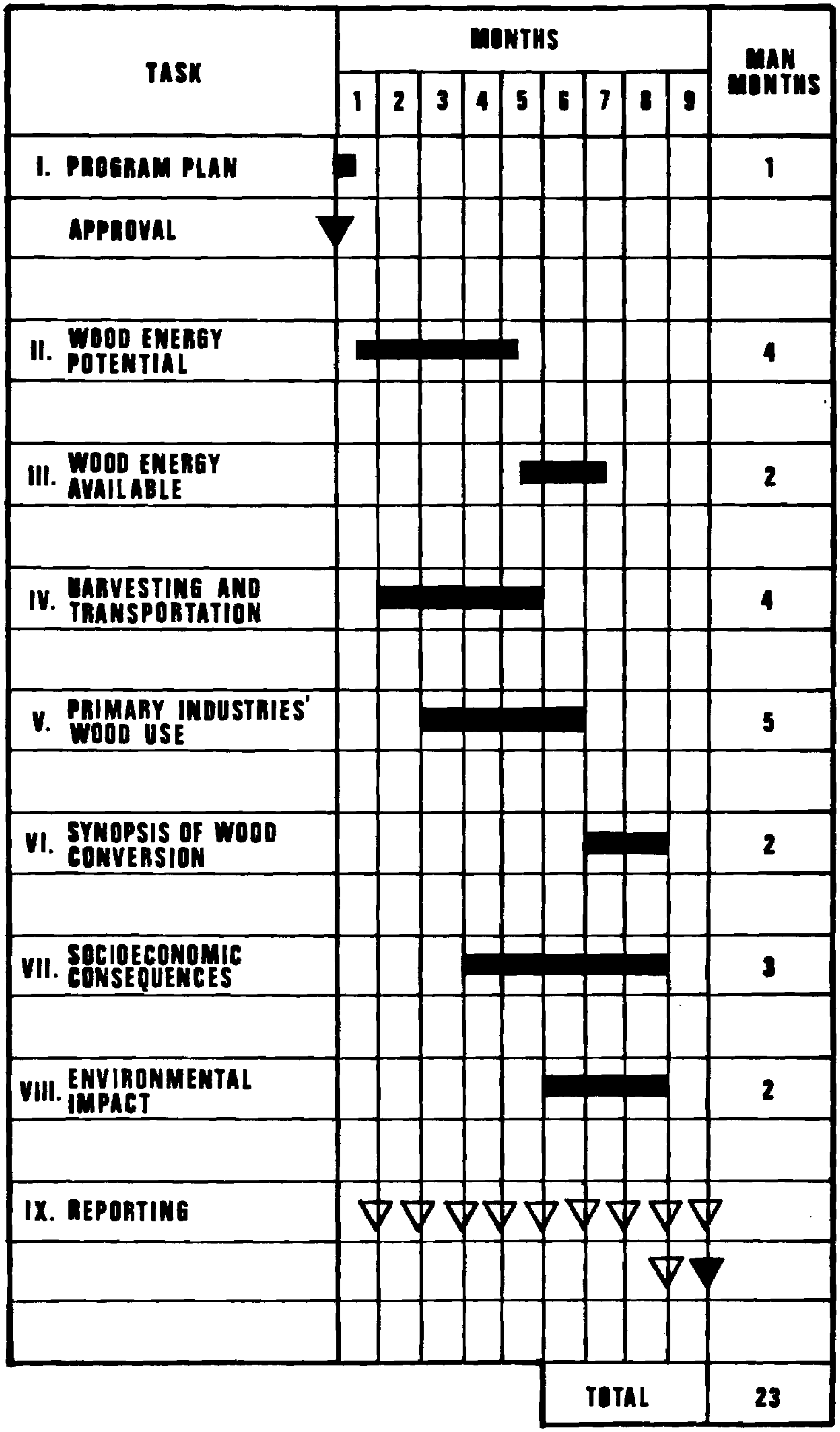
John J. Owen III
Research Engineer

JJO/dlm

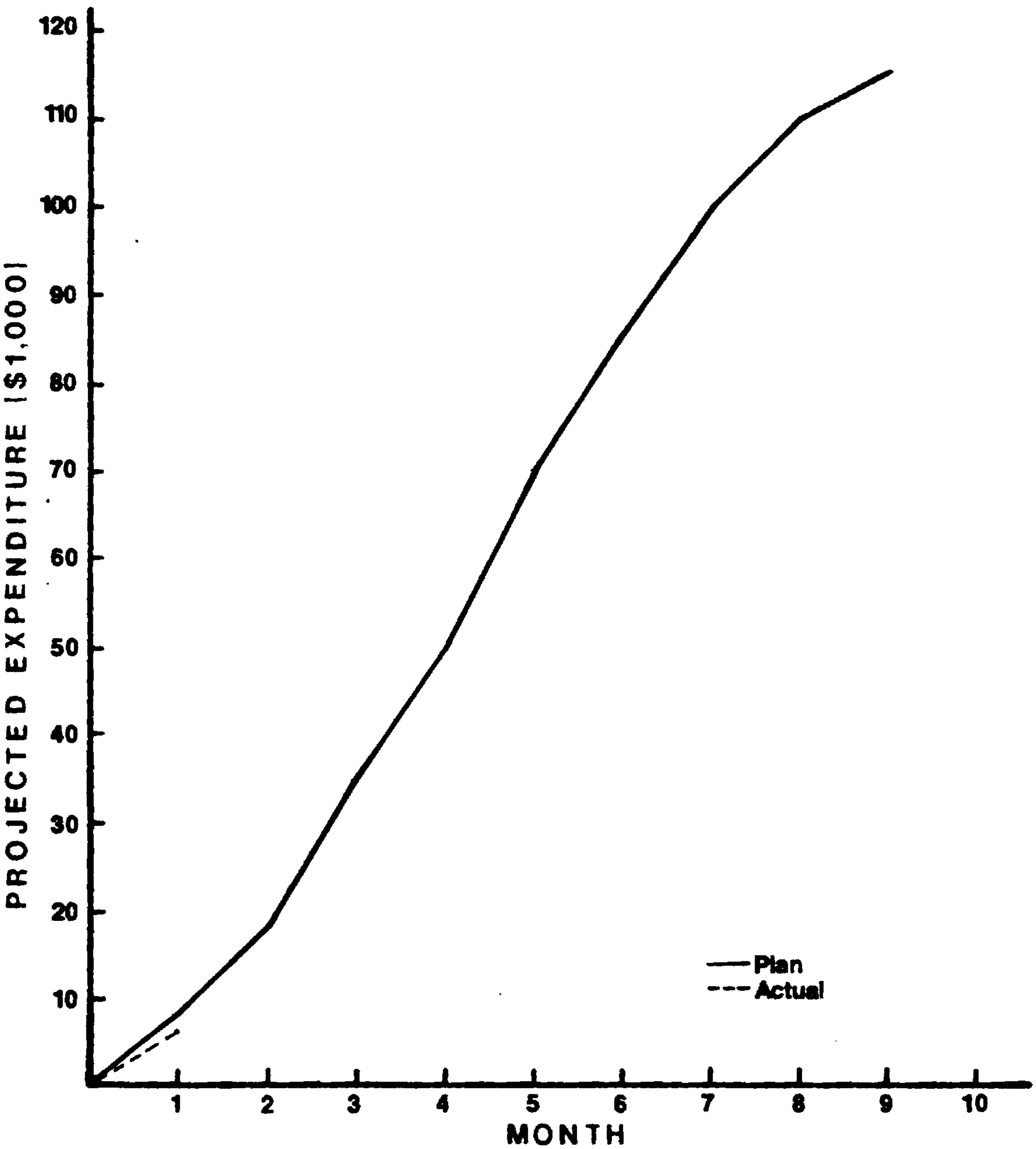
Enclosure

WOOD ENERGY POTENTIAL IN WEST VIRGINIA

PROJECT SCHEDULE - INITIATION ON JANUARY 1, 1979



WOOD ENERGY POTENTIAL IN WEST VIRGINIA
FUNDING PLAN



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ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

March 5, 1979

Mr. Paul R. Jenkins
Executive Vice President
Claude Worthington Benedum Foundation
Benedum-Tree Building
Pittsburgh, Pennsylvania 15222

Dear Paul:

During February we continued work on the study entitled "Wood Energy Potential in West Virginia". The following items were accomplished this month:

- We completed the potential wood supply estimate.
- We continued the harvesting and transportation investigation.
- We began the determination of wood energy actually available.
- We started an initial survey of potential industrial uses for wood energy.

During the month of March we plan to:

- Submit a draft of the potential wood supply chapter for your review.
- Continue the determination of wood energy actually available.
- Continue the harvesting and transportation investigation.
- Complete the initial survey of potential industrial uses for wood energy.
- Visit West Virginia for additional data collection.

This month we added Craig Wyville to the project team. Craig was formerly with the Environmental Protection Agency in Washington, D. C., and has industrial experience with Union Carbide in West Virginia. The enclosed Funding Plan indicates the project is proceeding as expected, and we have encountered no major problems.

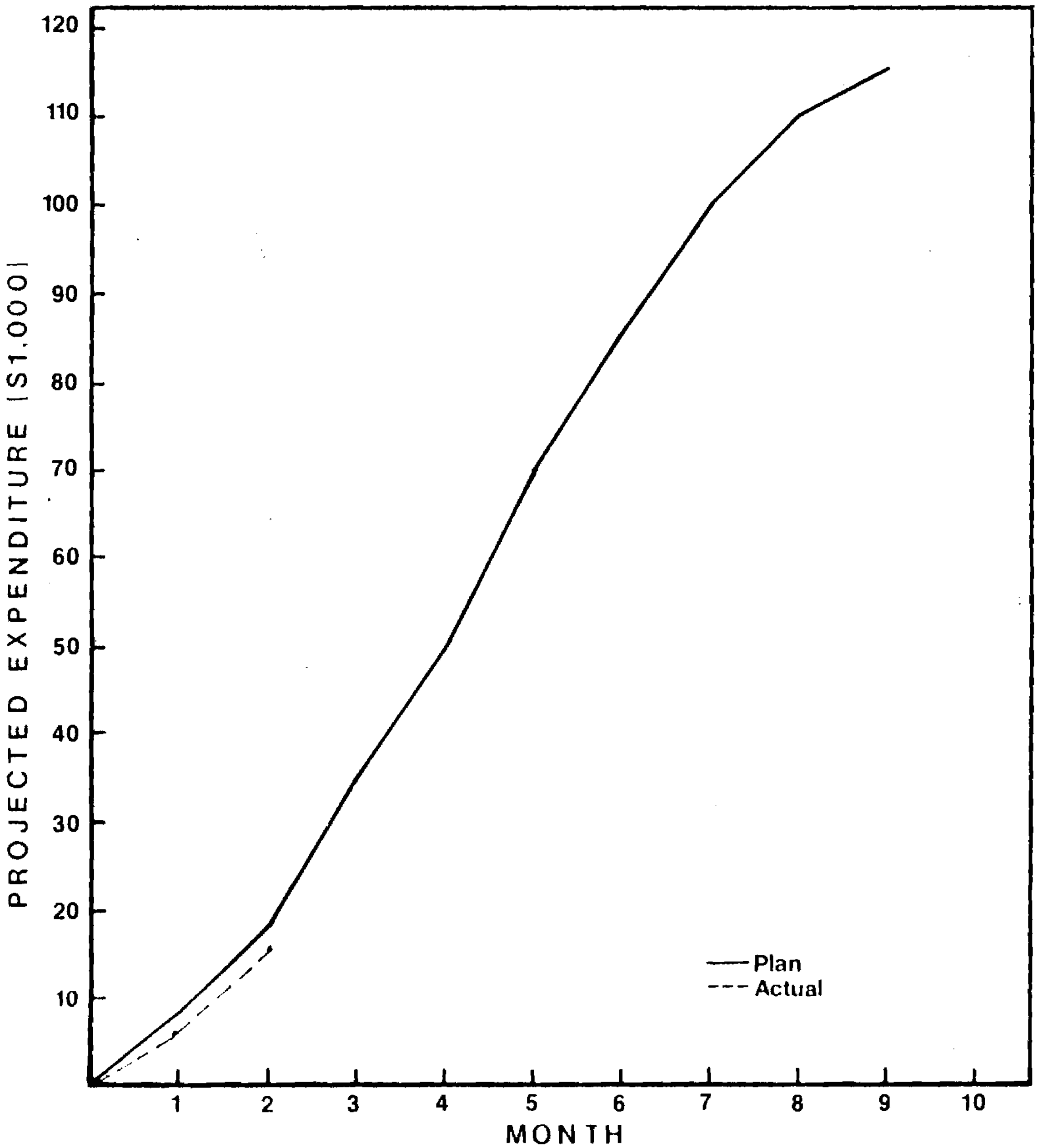
Sincerely yours,

J. L. Birchfield
Associate Director
Technology & Development Laboratory

JLB/dlm

Enclosure

WOOD ENERGY POTENTIAL IN WEST VIRGINIA
FUNDING PLAN



A-2297

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

~~March~~ April 5, 1979

Mr. Paul R. Jenkins
Executive Vice President
Claude Worthington Benedum Foundation
Benedum-Tree Building
Pittsburgh, Pennsylvania 15222

Dear Paul:

During March we continued work on the study entitled "Wood Energy Potential in West Virginia". The following tasks were accomplished this month:

- We continued the determination of wood energy actually available.
- We continued the harvesting and transportation investigation.
- We completed the initial survey of potential industrial uses for wood energy.
- We visited West Virginia for additional data collection.

During the month of April we plan to:

- Continue the determination of wood energy actually available.
- Continue the harvesting and transportation investigation.
- Continue the evaluation of potential industrial uses for wood energy.
- Begin the evaluation of socioeconomic consequences of expanded wood utilization.
- Visit West Virginia to interview major land holders and forest industry representatives.

Mr. Paul R. Jenkins

We have decided to combine the discussions of wood energy potential and wood energy available into a single chapter of the report, so a draft submission will be delayed until the wood energy available determination is complete. The project is continuing its satisfactory schedule and budget performance, with no significant problems.

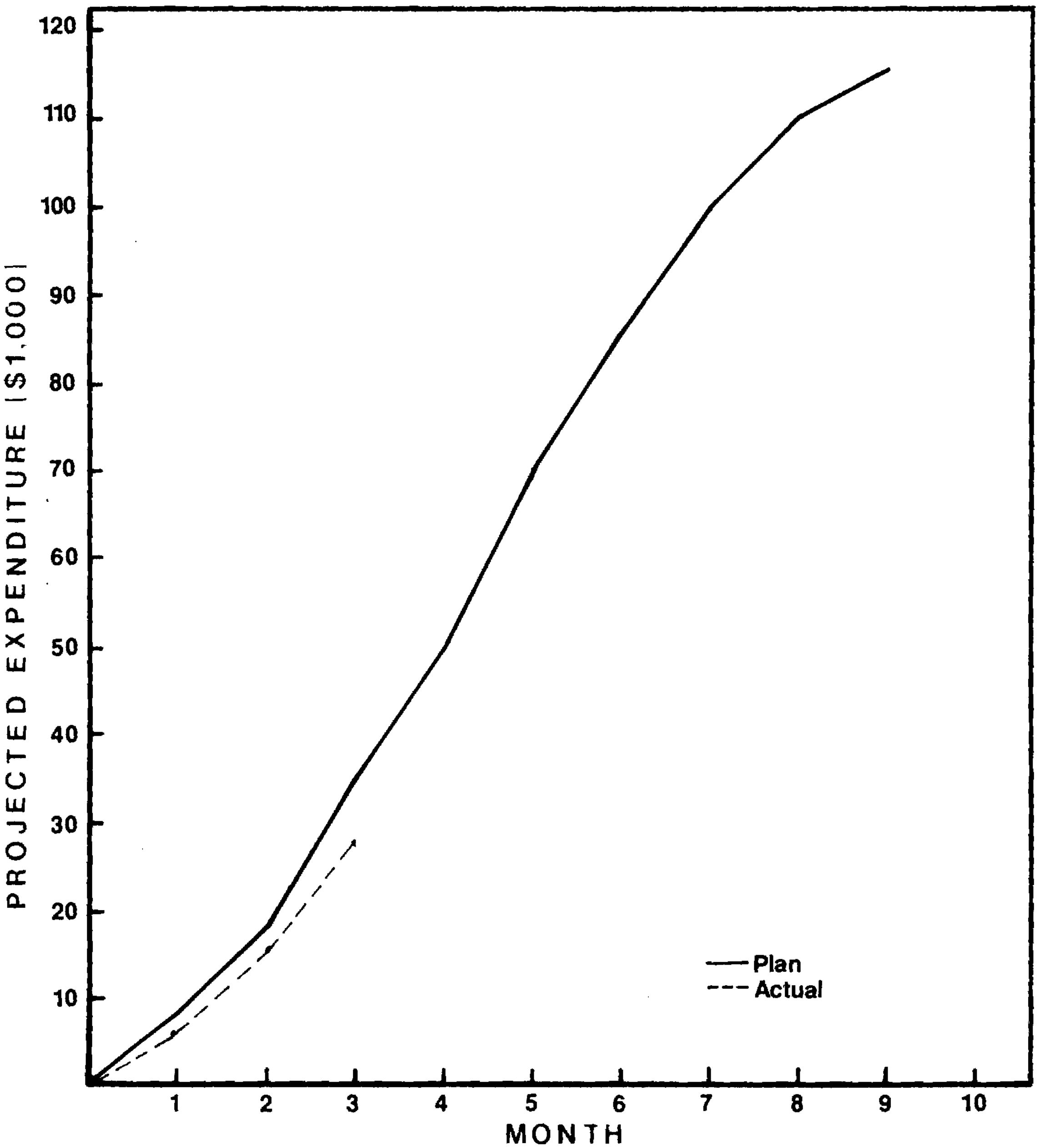
Sincerelv vours.

J. L. Birchfield
Associate Director
Technology & Development Laboratory

JLB/mch

enclosure

WOOD ENERGY POTENTIAL IN WEST VIRGINIA
FUNDING PLAN



A-2297

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

May 7, 1979

Mr. Paul R. Jenkins
Executive Vice President
Claude Worthington Benedum Foundation
Benedum-Tree Building
Pittsburgh, Pennsylvania 15222

Dear Paul:

During April we continued work on the study entitled "Wood Energy Potential in West Virginia". The following tasks were accomplished this month:

- We continued the determination of wood energy actually available.
- We continued the harvesting and transportation investigation.
- We continued the evaluation of potential industrial uses for wood energy.
- We began the evaluation of socioeconomic consequences of expanded wood utilization.
- We visited West Virginia to interview Westvaco, Georgia Pacific, and Pocahontas representatives, and made field trips to several wood harvesting sites.

During the month of May we plan to:

- Continue the determination of wood energy actually available.
- Complete the harvesting and transportation investigation.
- Continue the evaluation of potential industrial uses for wood energy.
- Continue the evaluation of socioeconomic consequences of expanded wood utilization.

We have added Mr. Larry Fisher to our project staff with an initial assignment in the socioeconomic and environmental investigations. He is pursuing a Ph. D. in Economics and has several years experience with the Environmental Protection Agency. The project is continuing its satisfactory schedule and budget performance, with no significant problems.

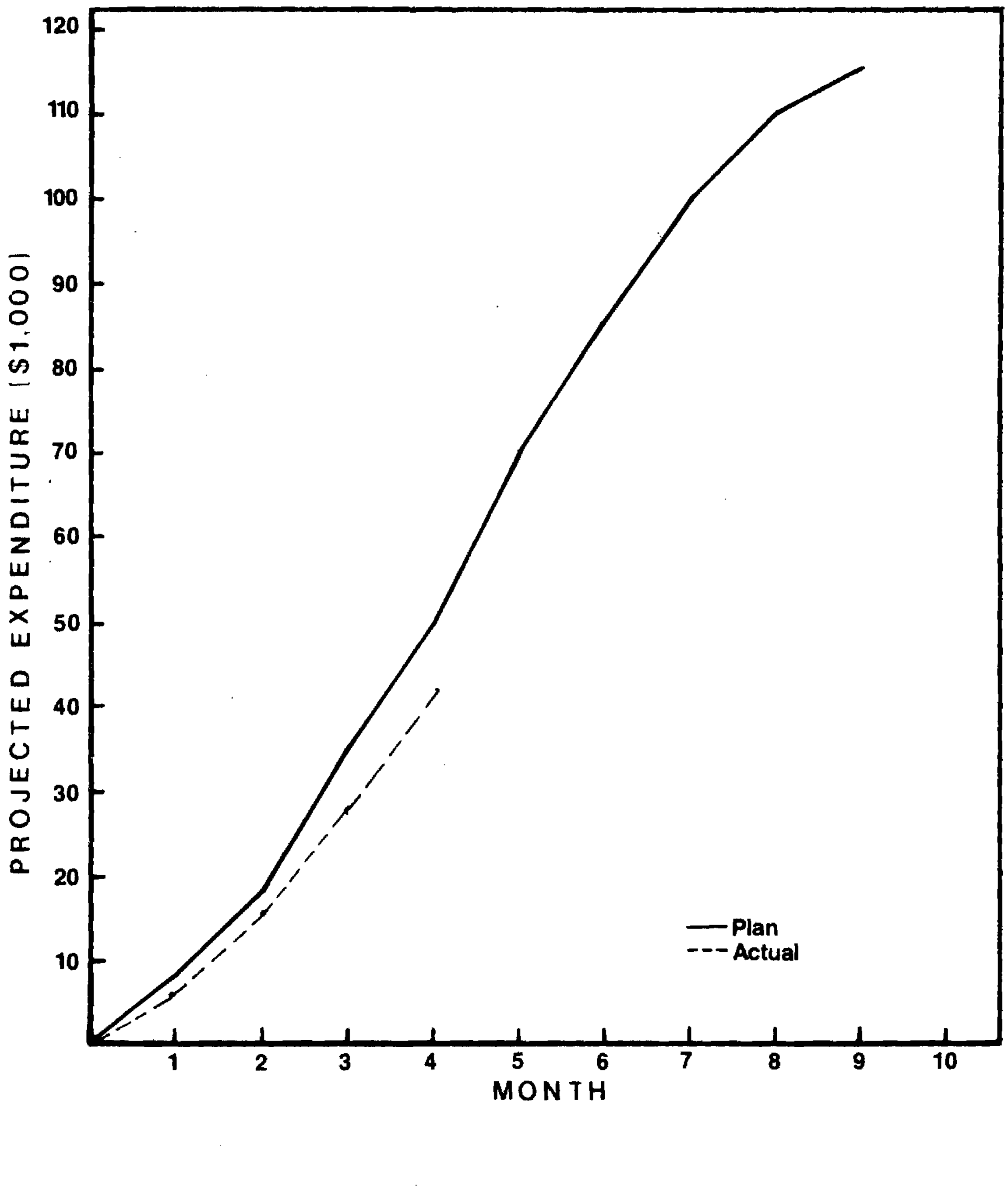
Sincerely yours,

J. L. Birchfield
Associate Director
Technology & Development Laboratory

JLB/dlm

Enclosure

WOOD ENERGY POTENTIAL IN WEST VIRGINIA
FUNDING PLAN



A-2297

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

June 4, 1979

Mr. Paul R. Jenkins
Executive Vice President
Claude Worthington Benedum Foundation
Benedum-Tree Building
Pittsburgh, Penn 15222

Dear Paul:

During May we continued work on the study entitled "Wood Energy Potential in West Virginia." The following tasks were accomplished this month:

- We continued the determination of wood energy actually available.
- We completed the harvesting and transportation investigation.
- We continued the evaluation of potential industrial uses for wood energy.
- We continued the evaluation of socioeconomic consequences of expanded wood utilization.

During the month of June we plan to:

- Continue the determination of wood energy actually available.
- Continue the evaluation of potential industrial uses for wood energy.
- Continue the evaluation of socioeconomic consequences of expanded wood utilization.

As we previously discussed, the program will be expanded to include a seminar for presentation of the study results. Since the data is organized by Planning and Development Region, we will work with Dan Green to select a suitable Region for one seminar. Officials from the remaining Regions would be encouraged to attend, so that they might undertake a similar presentation in their own Region. A single seminar can be included within our current budget but would extend the project through November, 1979, when the seminar would be conducted. We will prepare materials and provide staff members to explain the results. We are assuming that a suitable public facility can be utilized without charge.

I am enclosing a revised program plan that reflects this latest modification. If you have any suggestions for the seminar, or wish to discuss its emphasis, please give me a call.

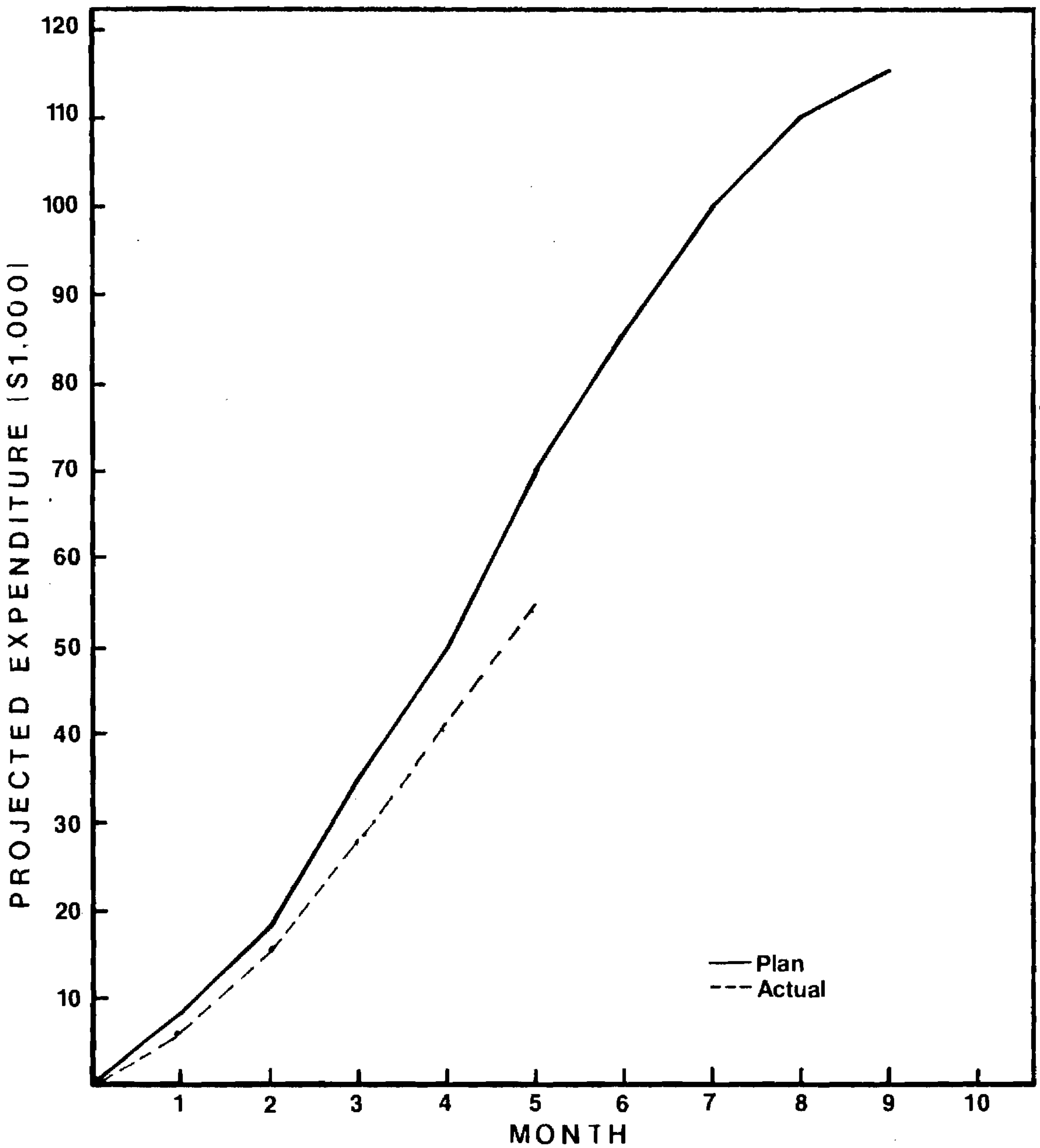
Sincerely yours,

J. L. Birchfield
Associate Director
Technology & Development Laboratory

JLB/mch

Enclosure

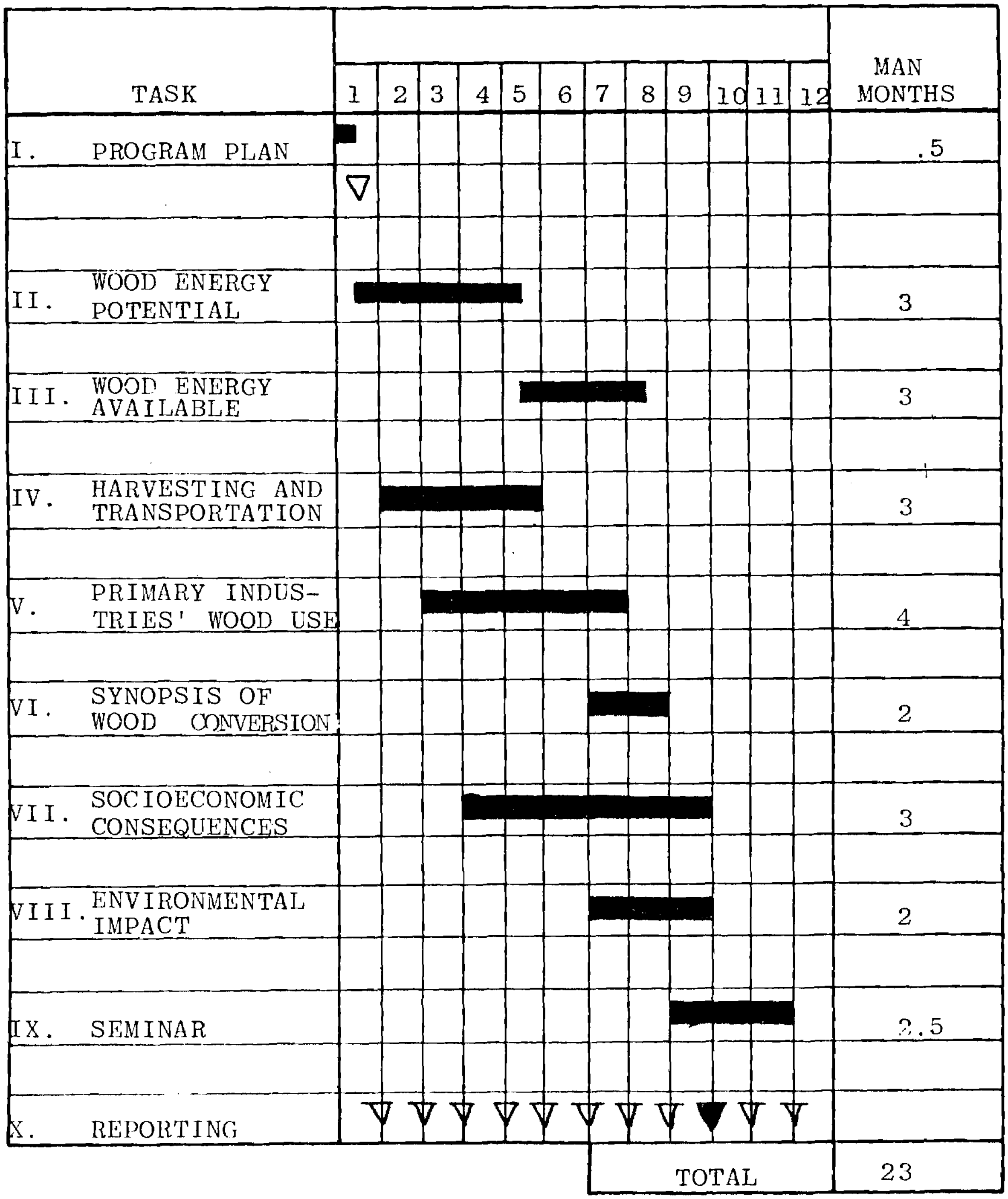
WOOD ENERGY POTENTIAL IN WEST VIRGINIA
FUNDING PLAN



PROJECT PLAN

WOOD ENERGY POTENTIAL IN WEST VIRGINIA

PROJECT SCHEDULE - INITIATION ON JANUARY 1, 1979



Project Director

Laboratory Director

A-2297

ENGINEERING EXPERIMENT STATION

GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

August 3, 1979

Mr. Paul R. Jenkins
Executive Vice President
Claude Worthington Benedum Foundation
Benedum-Tree Building
Pittsburgh, Pennsylvania 15222

Dear Paul:

During July we continued work on the study entitled "Wood Energy Potential in West Virginia." Most of the research and data collection has been completed, so we are beginning to prepare the final report.

I am enclosing an outline of the new task we discussed. The seminar will be conducted in November and Carol Aton will contact you in the near future to review potential dates, locations, and participants. We can prepare and present the material within the project budget, but may need some assistance with the facility, refreshments, and production of the final report for distribution to participants.

Sincerely,

J. L. Birchfield
Project Director

enc.

Task IX, Seminar

During the month of November, we will conduct a seminar in West Virginia to present the results of the study performed for the Benedum Foundation. A discussion with the Foundation will be held in August to establish the date, location, and attendees. The audience should include representatives of the Foundation, Planning and Development Regions, major industries, state and federal legislators, governor's staff and universities. We will prepare a slide presentation covering the national and West Virginia aspects of wood energy, distribute copies of the final report, and conclude with a question and answer session. The cost of the facility, refreshments, and expanded production of the final report may require additional support from the Foundation.

PROJECT PLAN

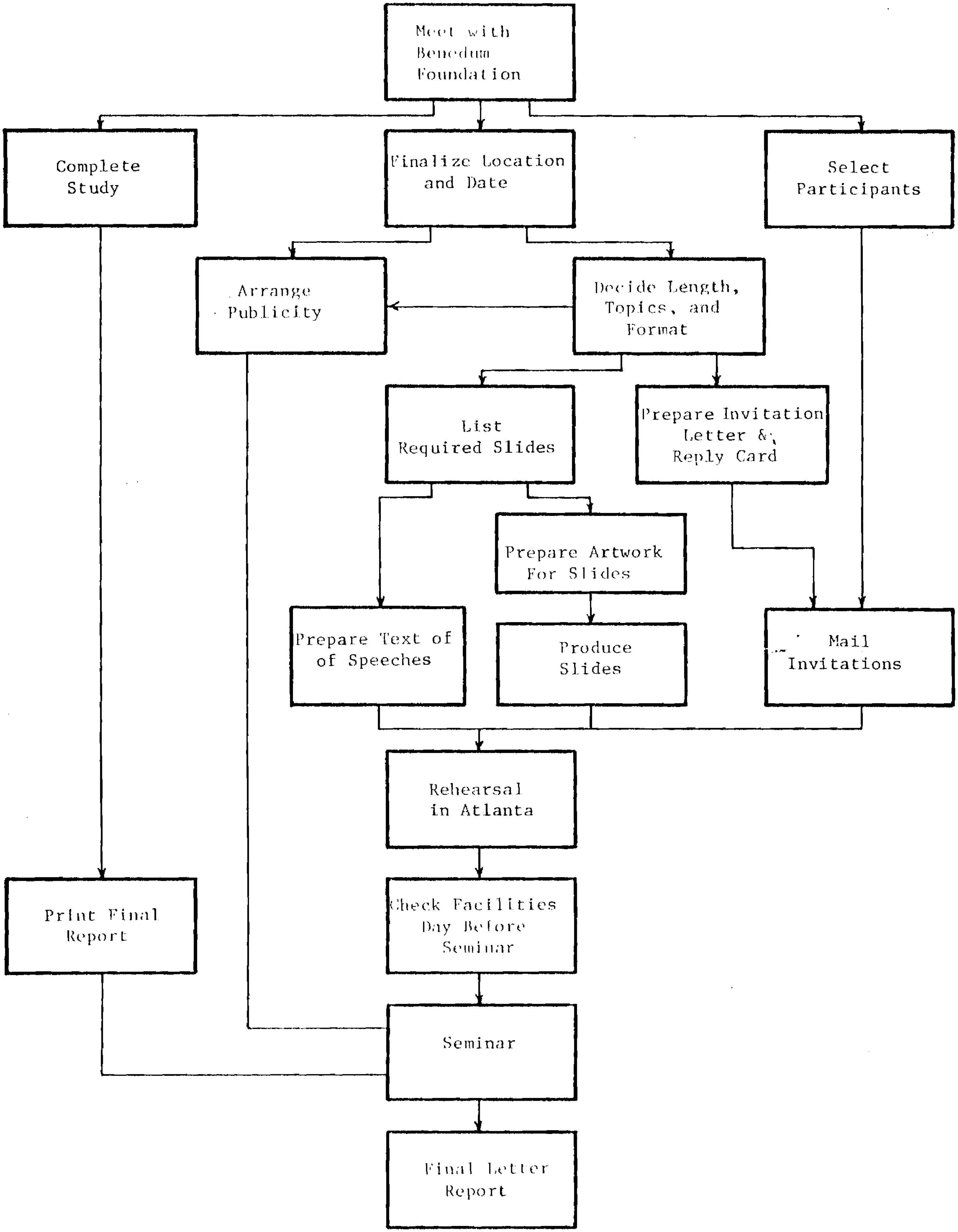
WOOD ENERGY POTENTIAL IN WEST VIRGINIA

PROJECT SCHEDULE - INITIATION ON JANUARY 1, 1979

	TASK	1	2	3	4	5	6	7	8	9	10	11	12	MAN MONTHS
I.	PROGRAM PLAN													.5
II.	WOOD ENERGY POTENTIAL													3
III.	WOOD ENERGY AVAILABLE													3
IV.	HARVESTING AND TRANSPORTATION													3
V.	PRIMARY INDUSTRIES' WOOD USE													4
VI.	SYNOPSIS OF WOOD CONVERSION													2
VII.	SOCIOECONOMIC CONSEQUENCES													3
VIII.	ENVIRONMENTAL IMPACT													2
IX.	SEMINAR													2.5
X.	REPORTING													
													TOTAL	23

Project Director

Laboratory Director


Meet with Benedum Foundation
Complete Study
Finalize Location and Date
Select Participants
Arrange Publicity
Decide Length, Topics, and Format
List Required Slides
Prepare Invitation Letter & Reply Card
Prepare Artwork For Slides
Prepare Text of of Speeches
Produce Slides
Mail Invitations
Rehearsal in Atlanta
Print Final Report
Check Facilities Day Before Seminar
Seminar
Final Letter Report

A-3297

Georgia Institute of Technology
ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA 30332

September 10, 1979

Mr. Paul R. Jenkins
Executive Vice President
Claude Worthington Benedum Foundation
Benedum - Tree Building
Pittsburg, Pennsylvania 15222

Dear Paul:

During August, we finalized inputs to our study entitled, "Wood Energy Potential in West Virginia." The formal report is now being assembled and should be completed as scheduled.

Based on our discussion, we would like to have you visit on October 1. The report should be completed by then and we can discuss our findings in detail. Please let me know if I can be of assistance in making arrangements for your visit.

Sincerelv.

J. L. Birchfield
Project Director

Project A-2297

WOOD ENERGY POTENTIAL IN WEST VIRGINIA

by

Carol L. Aton

Lawrence P. Fisher

J. Craig Wyvill

Jerry L. Birchfield, Project Director

Technology Applications Laboratory
Engineering Experiment Station
GEORGIA INSTITUTE OF TECHNOLOGY

This report was prepared in discussion with the West Virginia Governor's Office of Economic and Community Development, the West Virginia Department of Natural Resources, West Virginia University, and the Northeastern Forest Experiment Station laboratories at Parsons and Princeton, West Virginia.

November 1979

Acknowledgements

During the development of this report, many hours were spent conversing with knowledgeable people about various subject areas. Since these are not specifically referenced in this report, the authors would like to acknowledge with sincere appreciation the special assistance and cooperation of the following: Ron Potesta and Judy Dyer of the Governor's Office of Economic and Community Development, Ralph Glover of the State Forester's Office, Joseph Smith of the U.S. Forest Service, Ed Maticks and Harry McIlvaine of Westvaco, Al Staggers of Georgia Pacific, and Connel Ware, Ron Gallimore, and Douglas Crickmer of the Pocahontas Land Corporation.

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I. PERSPECTIVE

In the early 1800's, wood was a major source of energy in the United States. Through the years it was gradually replaced by coal, then petroleum products, until today less than 2% of our energy comes from wood. Now, with variations in gas and oil supplies and tax incentives from the Energy Tax Act of 1978, wood is gaining favor once again as an alternate renewable energy source.

The standing forests of the United States comprise over 740 million acres, about one-third of the contiguous U.S. land area. The total energy content of this resource is about 300 quadrillion Btu's, or quads. The Northwest has 95 quads, mostly in Oregon and Washington; 90 are in the Southeast and South Central states; and 45 are in the Northeastern states. Of these three major resource areas, the forest growth rate is highest in the Southeast, next highest in the Northeast, and slowest in the Northwest. Today, the United States uses wood to supply about 1.1 quads of primary energy. Over 80% of that usage is concentrated in the forest products industry.

According to the U.S. Forest Service, 8.3 quads of energy wood are available but unused every year. Of this, 2.2 to 4.4 quads are realistically recoverable. With steady increases in utilization of forest wastes and manufacturing residues, wood might someday provide as much as 7% of our national energy budget. That is the equivalent of $19.4 billion of oil imports at $22 per barrel.

This study indicates that a substantial West Virginia resource is currently being underutilized. Over three quarters of the state is covered by commercial forestland, much of which contains trees unsuitable for lumber products. One in every four hardwood trees and one in every eight softwood trees are unmerchantable. These trees have great potential as a resource base for a wood energy industry in the state, and removing them will increase forest productivity for the future by making room for higher quality commercial trees. Most of the fuel material can be acquired through multipurpose harvesting of mature timber stands. Trunks of the best trees can be utilized for lumber, with the remaining tops and cull trees chipped for pulp and fuel. This study indicates that 23% of the wood annually available for energy in the state can be recovered without impacting future demands for timber products.

Use of this alternate energy source will provide an economic boost to the state of an estimated $291.5 million, a 2.9% increase based on West Virginia income of nearly $10 billion in 1976. The need for increased harvest and transport operations will create over 2,500 new jobs directly plus such additional jobs as equipment sales and service personnel, administrative personnel, and wood-handling managers at plant sites. Property values will increase as well, since many acres currently standing idle with low-grade timber would become a resource for fuelwood.

The Energy Consumption pattern for the State of West Virginia in 1977 was:

Electric Utility	--	48.8%
Industrial	--	30.8%
Transportation	--	11.2%
Residential	--	6.5%
Commercial	--	2.7%

This report deals mainly with the use of wood for energy in the industrial and transportation sectors. Electric utilities are large-scale users of coal, which cannot be replaced economically by wood. Use of wood in the residential and commercial sectors is certainly feasible but would not entail high technology harvest and conversion equipment.

The following table shows cost figures for industrial fuels in West Virginia. The 1979 coal and distillate oil prices are representative term costs. Spot prices in these two areas indicate coal prices have temporarily leveled out, while distillate oil prices can be expected to increase further.

WEST VIRGINIA ENERGY FUEL PRICES
FOR THE INDUSTRIAL SECTOR
($/million Btu)

	1977	1979
Coal	$1.47*	$1.48**
Natural Gas	$1.92	$3.00
Residual Oil No. 6	$2.23	$3.25***
Distillate Oil No. 2	$3.19	$3.40
Purchased Electricity	$6.40	$8.20

* Since no value was available for industrial sector alone, this value is the average for West Virginia coal in 1977 (all grades).

** Steam coal only - price reflects an average term cost for 0% to 2% sulfur grade.

*** Average cost of both 1% and 2% sulfur grade

Source: West Virginia Fuel and Energy Office, November 1979.

The cost of wood chips in West Virginia is $2.67 per million Btu's for skidding and $3.11 per million Btu's for cable harvesting. These numbers reflect stumpage at $1.20 per ton, a mix of 20% flatland and 80% hillside operations, and transportation by truck 50 miles one way. With oil and natural gas predicted to top $4.00 per million Btu's by 1995, wood should compare favorably with liquid and gaseous fuels.

The technologies associated with converting wood to energy for such applications are in various stages of development.

Direct Combustion is the burning of fuel in the presence of oxygen for use as a direct heat source. The forest products industry has used direct combustion for many years in an effort to reduce its waste disposal problems. The disadvantages of these systems are the large combustion volumes required and particulate emissions. Also, retrofitting existing oil or gas boilers is very difficult, and conversion to direct combustion requires a substantial capital investment.

Fluidized Bed Combustion is a relatively new technology that immerses the fuel (liquid, gas, or solid) in a bed of sand or similar material. The bed is "fluidized" by blowing air up through the material, causing it to assume a suspension resembling a boiling liquid. While originally very attractive for burning coal due to the capability for removing sulfur, fluidized beds also show promise in handling wood fuel of high moisture content and irregular shape.

Pyrolysis is the decomposition of organic materials with heat in the absence of oxygen. The char, oil, and gas produced by pyrolysis of wood can be used as fuel or chemical feedstocks. Pyrolysis is not widely used in the industrial sector, but could have application wherever the disposal of organic waste and the need for fuel occur simultaneously.

Densification is the compacting of small particles into a molded shape. The process was first used to produce animal feed. It now shows promise of providing a dry, uniform, easily stored, and conveniently shipped fuel from sawdust or other biomass residues.

Gasification is the thermal conversion of wood to a gas that can be burned like natural gas or oil. Dry wood chips and pellets make excellent gasifier fuels. With the advent of total tree chipping and pelletization equipment, wood gasification holds promise for the industrial sector. Wood gasification techniques, however, need to be refined. Grate design, feed methods, ash removal, and wood gas enrichment are all areas requiring further development.

Alcohol can be produced from wood via hydrolysis or fermentation. It is an old concept, but one that was not economical until petroleum feedstocks became short in supply and high in price. Ethanol, a form of alcohol, is of primary importance. Ethanol-gasoline mixtures can be used as a transportation fuel with little engine modification.

Wood gasification has potential for supplementing the natural gas requirements of the industrial sector. This process can be used to retrofit boilers that are designed to burn only gas or oil. This application is particularly attractive because West Virginia has been a net importer of natural gas since 1972. Alcohol production from wood will allow West Virginia the opportunity to compete in the newly developing gasohol market. Research is still being conducted in this area, but it shows great promise.

The expanded use of West Virginia's wood resource will not harm the environment if proper care is taken in harvesting the wood and in converting the wood to energy. Following improved procedures for multipurpose forest management will ensure that energy wood harvest is compatible with watershed, wildlife, and other forest objectives. Off-the-shelf pollution control equipment can be used on conversion technologies that, if uncontrolled, do not meet air pollution emission standards.

Wood energy is already being used with success. Russell Mills, a textile manufacturer in Alabama, provides all of its steam load in summer and half in winter by firing a steam plant with sawmill residue. Merry Brick Corporation in Georgia saves $4,200 per week in fuel costs with a brick-curing kiln that was converted from natural gas to sawdust. Galaxy Carpet in Tennessee installed a 250 hp multifuel boiler for process steam that can burn oil, coal, wood, and waste carpet scraps. They expect a 2½-year payback using a mixture of wood or coal and carpet scraps as fuel.

West Virginia's wood resources are sufficient to warrant a demonstration program of wood as an energy source. Short-term benefits would be increased employment and increased economic activity. Long-term benefits would be greater productivity on the 11.5 million acres of commercial forestland. Wood energy potential in West Virginia should not be overlooked.

II. FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

Summary of Findings and Conclusions

The primary focus of this study was the extent to which waste wood is available in West Virginia, how it might be utilized commercially, and the impact that the development of a wood energy industry might have on the state. The significant findings and conclusions of this study are summarized as follows:

1. The total inventory of forest biomass in West Virginia generates 34.1 million tons of green wood available for energy every year. Of this, 23% or 7.8 million tons are readily recoverable without impacting future demands for timber products. This is equivalent to 67 trillion Btu's of energy per year.

2. The projected income effect for harvesting and delivering this amount of wood fuel is $168 million in annual fuel sales revenue, or a $291.5 million impact on yearly state income. This represents a 2.9% increase based on West Virginia income of $9.94 billion in 1976.

3. Harvest and delivery of 7.8 million tons of wood fuel would create over 2,500 new jobs directly, plus such additional jobs as equipment sales and service personnel, administrative personnel, and wood-handling managers at plant sites. Indirect jobs created would include construction and production workers involved in plant conversions and worker support industries such as insurance and food supply.

4. Use of mechanized equipment in West Virginia harvesting is severely limited by terrain. Two-thirds of the state has a slope greater than 25%.

5. Truck is the most economically practical means of transporting energy wood in West Virginia over short distances. Barge transportation costs less than truck per ton mile, but is severely restricted by geography in its service area necessitating costly cargo transfers by truck or rail from field sites. Barging, therefore, is considered useful only over long distance hauls to industries in the major river valleys. Rail rates, on the other hand, are higher than truck for short distance hauling of fuelwood. The breakeven point for rail versus truck is 175 miles, accounting for necessary cargo transfers.

6. The cost of a typical whole-tree chipping operation in West Virginia for three harvest scenarios is:

   Skidding -- $2.67 per mmBtu's
   Cable -- $3.11 per mmBtu's
   Helicopter -- $5.21 per mmBtu's

   These numbers reflect stumpage at $1.20 per ton, a mix of 20% flatland and 80% hillside operations, and transportaion by truck 50 miles one way.

7. The expanded use of West Virginia's wood resources will not harm the environment if proper care is taken in harvesting the wood and in converting the wood to energy. Following improved procedures for multipurpose forest management will ensure that energy wood harvest is compatible with watershed, wildlife, and other forest objectives. Off-the-shelf pollution control equipment can be used on conversion technologies that, if uncontrolled, do not meet air pollution emission standards.

8. Statewide, manufacturing residues from primary sources account for less than 1% of the energy wood available because utilization has increased dramatically over

the last 10 years. On a local level, however, residues that are presently disposed of may provide an important source of low-cost energy.

9. Wood gasification holds potential for supplementing the natural gas requirements of the Chemical and Stone, Clay and Glass industrial sectors of the state. This application is particularly attractive because West Virginia has been a net importer of natural gas since 1972 with these two sectors alone consuming 29% of all natural gas used in the state in 1974.

10. Wood usage in the Primary Metals industry needs further research. Unfortunately, demands for natural gas by this sector are in blast furnace operations where special fuel requirements restrict simple combustion of wood.

11. Ethanol production from wood will allow West Virginia the opportunity to compete in the newly developing gasohol market. Research is still being conducted in this area, but it shows great promise.

12. Wood mixing with coal is an applications area where further research is needed. Preliminary evaluations have shown that wood can reduce the sulfur content of coal, improve fly ash cleanup, and when properly prepared, not influence the rating of coal furnaces in which the mixture is used. This could be a significant marketing tool for coal sales in areas of the country where environmental considerations are reducing demand for certain types of West Virginia coal.

13. Wood can be expected to compete economically with natural gas in the industrial sector due to current high gas prices and future pricing and demand forecasts. Wood should not compete economically with

coal since coal prices are much lower than wood, and coal distribution and handling network costs have already been invested.

Recommendations

Proceeding from the overall conclusion that, based on the evidence examined in this study, the potential exists for the development of a substantial wood energy industry in West Virginia, it is recommended that the following steps be taken to more precisely define this potential and to stimulate the establishment and growth of wood energy activities in the state:

1. Simulate wood energy as an industrial sector in the existing West Virginia Input-Output Model, based on the extent of income increase that expanded wood use can create.

2. Investigate the economic impacts of making rail rates for fuelwood chips more equitable with other discount fares for favorable products.

3. Develop and implement an incentive program for energy wood harvesters. Simultaneously, demonstrate the feasibility of wood energy systems within the industrial sector of the state.

4. Study the improvements in design of harvesting equipment for use on West Virginia hillsides.

5. Explore the technological and economic potential of wood usage in the Primary Metals industry as a substitute for current natural gas consumption.

6. Investigate the feasibility of mixing wood chips with West Virginia coal to reduce emissions and improve salability of West Virginia coal.

7. Determine the viability of setting up an ethanol production facility in West Virginia to reduce consumption of gasoline in the transportation sector.

8. Set up a wood gasification system at a West Virginia plant to demonstrate feasibility.
9. Provide direct technical assistance to industries considering the use of wood energy.

III. SUPPLY OF WOOD ENERGY RESOURCES IN WEST VIRGINIA

Background of Wood Use

In the early years of this country's development, wood was the dominant source of fuel for the nation. The economy of 1800 overwhelmingly favored the use of wood. It could be obtained readily and had to be cut anyway if land was to be cleared for the primary business of agriculture. It is no surprise, therefore, that with the exception of the mechanical energy demands of industry (supplied by wind and water power), wood provided essentially all of the nation's energy needs, including heating the home, cooking meals, smelting iron, and driving steamboats and trains.

Between 1830 and 1850, the rapidly expanding nation began turning to other energy sources as wood supplies near major users began to dwindle. The first such departure from wood occurred in the iron industry where wood-based charcoal became increasingly expensive, accounting for nearly 62% of the total cost of producing iron. Growing demand for less expensive smelting fuel culiminated in the opening of several coal fields in 1830. The iron industry immediately began the transition to coke-produced iron. By 1850 anthracite iron cost one-fifth as much as charcoal iron, and Pennsylvania had almost as many anthracite furnaces as charcoal furnaces.

Wood as a fuel source peaked between 1850 and 1870. By 1860, the railroads were consuming 6 million cords of wood per year and steamboats, 3 million cords. Yet rapid industrialization and the growing need for additional inexpensive energy led to further exploration of coal. By 1865, the railroads were relying on coal to supply 25% of their energy. During this period, two new forms of energy began to be exploited -- oil and gas. As early as 1841, William Tompkins began the first commercial use of natural gas deposits that plagued his West

Virginia salt fields; he used it to evaporate salt brine. The first West Virginia oil well was drilled in May 1860.

The period from 1870 to 1920 saw the gradual demise of wood as the primary energy source for the nation. Three factors played an important role in this decline:

1. The dramatic rise in demand for timber by the forest products industries,
2. The creation of a national economy with a national energy market (wood continued to remain a regional energy source), and
3. The rapid growth in national energy demand that far outpaced the ability of wood to be harvested and shipped in sufficient quantities.

The single most important factor that reduced the availability of fuelwood was the growth of the forest products industries. Demand caused the harvest of wood for products to exceed the harvest of wood for fuel. Lumber companies accelerated their usage of timber as a result of the discovery of the bandmill in 1881. By 1909, West Virginia was producing a record 1.4 billion board feet of lumber (Figure III-1). In the meantime, pulp and paper companies had begun replacing rags with wood as their primary feedstock. The virgin forests were slowly disappearing under unbridled exploitation. No effort was being made to conserve this valuable resource.

The forest suffered immensely as this exploitation continued. Forest fires occurred with regularity. Started primarily by sparks from logging trains, they ravaged the forest floor, preventing the growth of new saplings. Without adequate vegetation, the soil quickly eroded and flash floods on major streams caused millions of dollars in property damage. The distance between major stands of trees and the timber mills began to increase as the forest area diminished. Transportation costs consequently increased the overall cost of harvested timber.

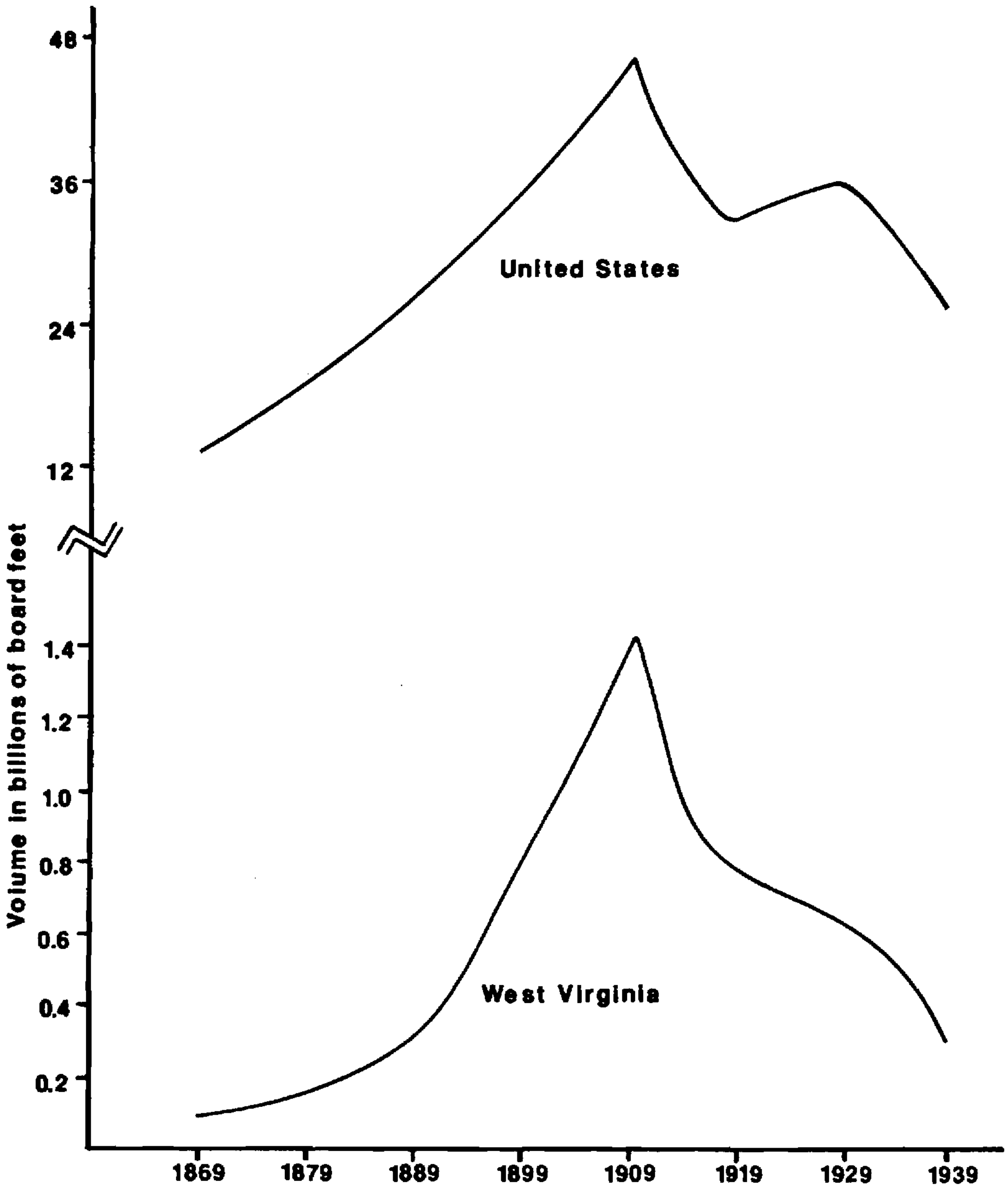


Figure III-1

LUMBER PRODUCTION IN WEST VIRGINIA
AND THE UNITED STATES, 1869-1939

Continued development of coal, natural gas, and oil supplies began to turn the nation to these concentrated energy forms to meet its soaring energy needs. By the 1920s, the forest products industries, able to pay the higher cost for fallen timber, claimed 67% of all wood harvested. Only the residential energy market remained dependent on fuelwood, and even this reliance was becoming uncertain. For a short time during the 1920s, sawdust and waste timber were marketed as an energy source. But the continued availabiltiy of inexpensive coal, oil, gas, and finally electricity brought an end to wood dominance in the residential energy market. Figure III-2 dramatizes the rapid growth in U.S. energy demand between 1870 and 1960 and emphasizes the decline in wood as an energy source during this period.

In 1961, West Virginia's lumber production, which accounted for nearly 75% of the total wood consumed from West Virginia's forests, slumped to 275 million board feet or less than one-fifth that of the record set in 1909. Concern over the plight of West Virginia's sagging wood industry prompted state leaders to call the first of several governor's conferences on wood utilization. The result was the beginning not only of investigations into new uses for wood, but also of better management of timber stands to promote new growth and better harvests.

In recent years, interest in wood energy has revived in the face of dwindling domestic petroleum supplies. Industry continues its search for sources of clean and reliable fuel. There can be no mistaking the renewed role that wood energy can play in the energy picture, as society begins to rediscover the potential of this renewable energy source.

Inventory of Forest Land and Wood Supply

Definitions. Every 10 years the U.S. Forest Service inventories timber on commercial forest land. Each tree is classified into one of the categories shown in Figure III-3. Well-formed

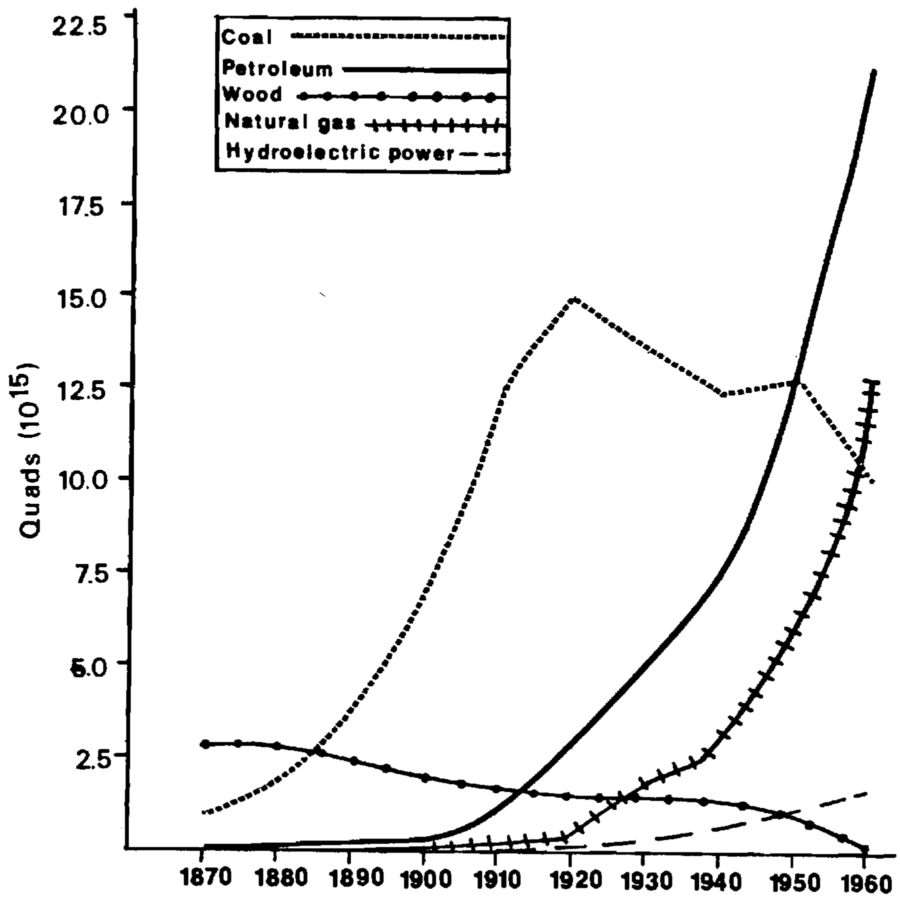


Figure III-2

HISTORICAL TREND OF ENERGY CONSUMPTION
IN THE UNITED STATES, 1870-1960

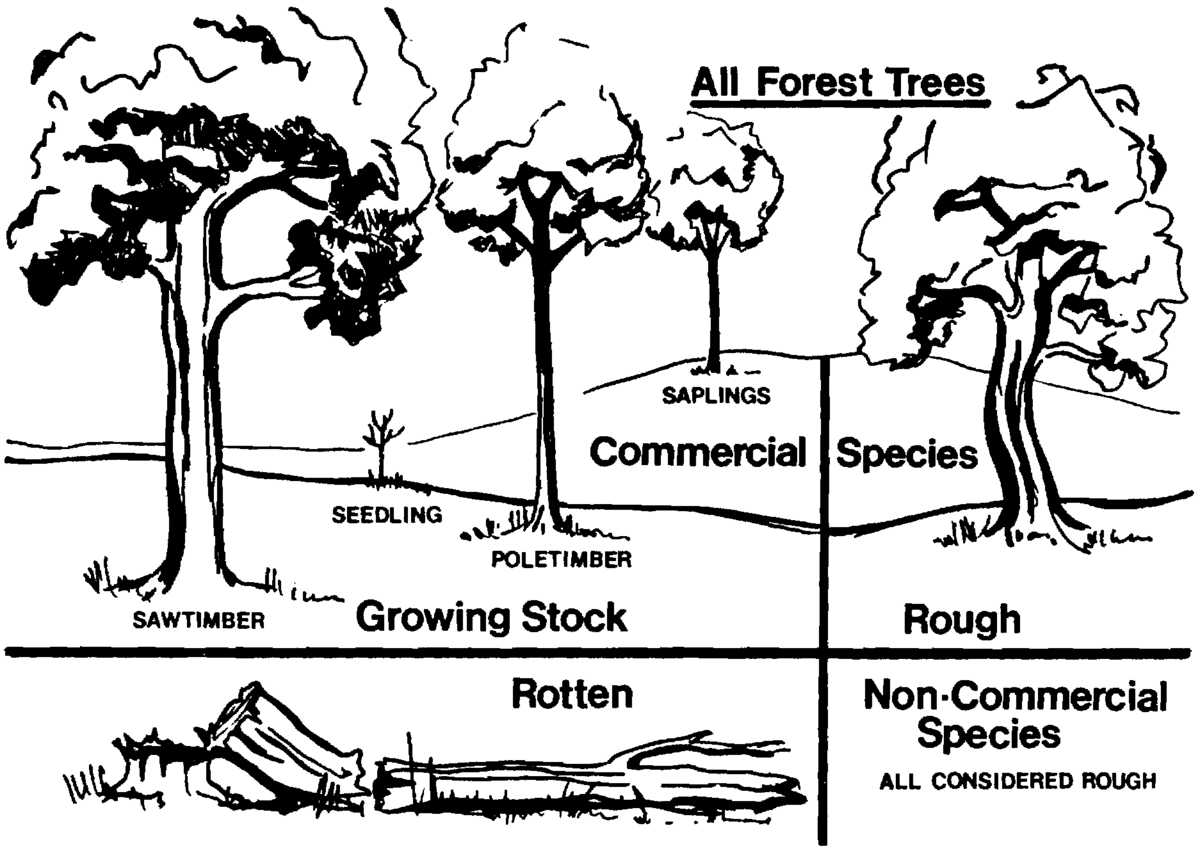


Figure III-3

CLASSIFICATION OF FOREST TREES

commercial species are divided into size classes reflecting suitability for timber products. All other trees are either rough trees (poorly formed or of non-commercial species) or rotten. Additional categories of wood that are inventoried by the Forest Service are shown in Figure III-4 and described below:

Logging residues	-	tops and limbs left in the forest after harvesting.
Other removals	-	timber removed for urban development, right-of-way clearing, or other nonproduct harvesting operations.
Manufacturing residues	-	waste products from lumber manufacturing operations.
Mortality	-	timber that dies from natural causes, such as disease and fire.

(See Appendix A for a complete list of Forest Service definitions.)

Foresters traditionally have been concerned with timber for products. Their inventory is taken in cubic feet or board feet relating directly to suitability for manufacturing lumber, furniture, posts and pilings, veneer, and plywood. As shown by the shaded areas in Figure III-5, only the straight portion of the stem from trees with diameters of 5 inches or more is included in the inventory.

Wood available for energy is all timber not used or grown for products, subject to recoverability.

Forest Land Patterns in the United States. Figure III-6 shows forest land as a percentage of state area for the United States. Of the 2.3 billion acres of land area in 1976, 488 million acres were classified as commercial forest land.

Forests of the Northwest are known throughout the world for their large softwoods. The Douglas fir ecosystem is the largest and most important timber producer, with redwood and hemlock-sitka spruce comprising the remaining types.

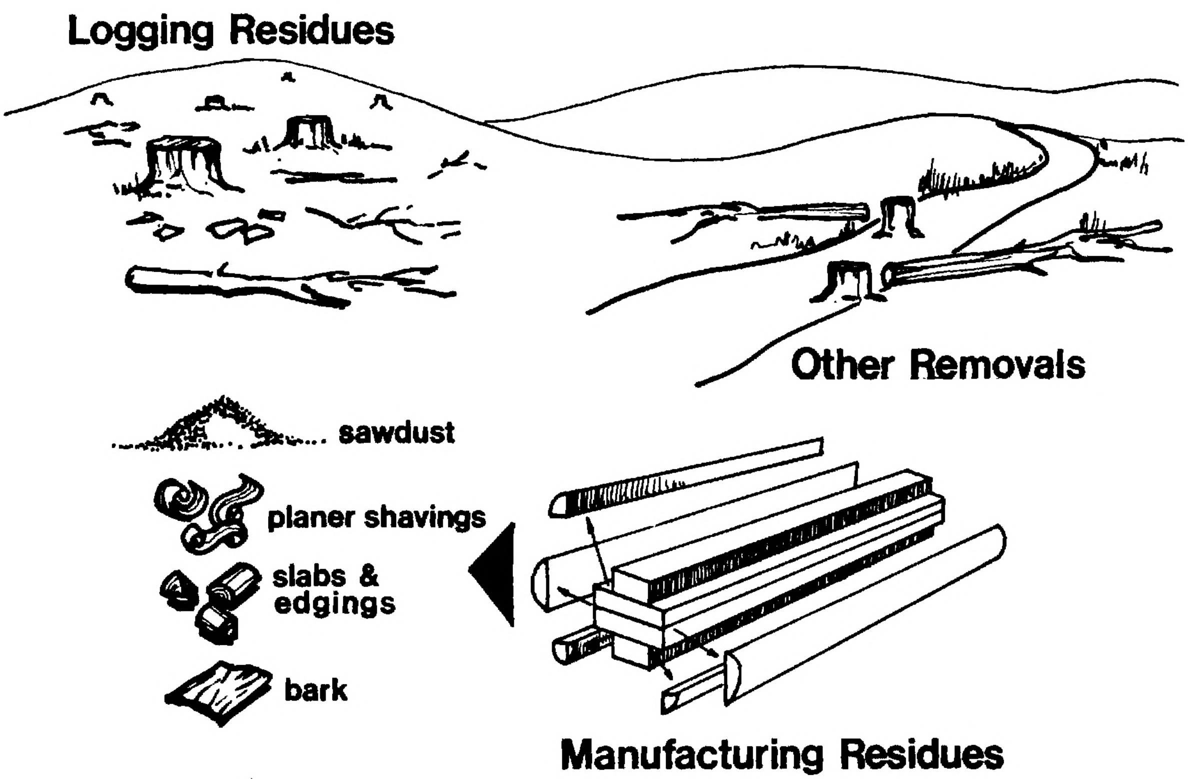


Figure III-4

CLASSIFICATION OF OTHER WOOD

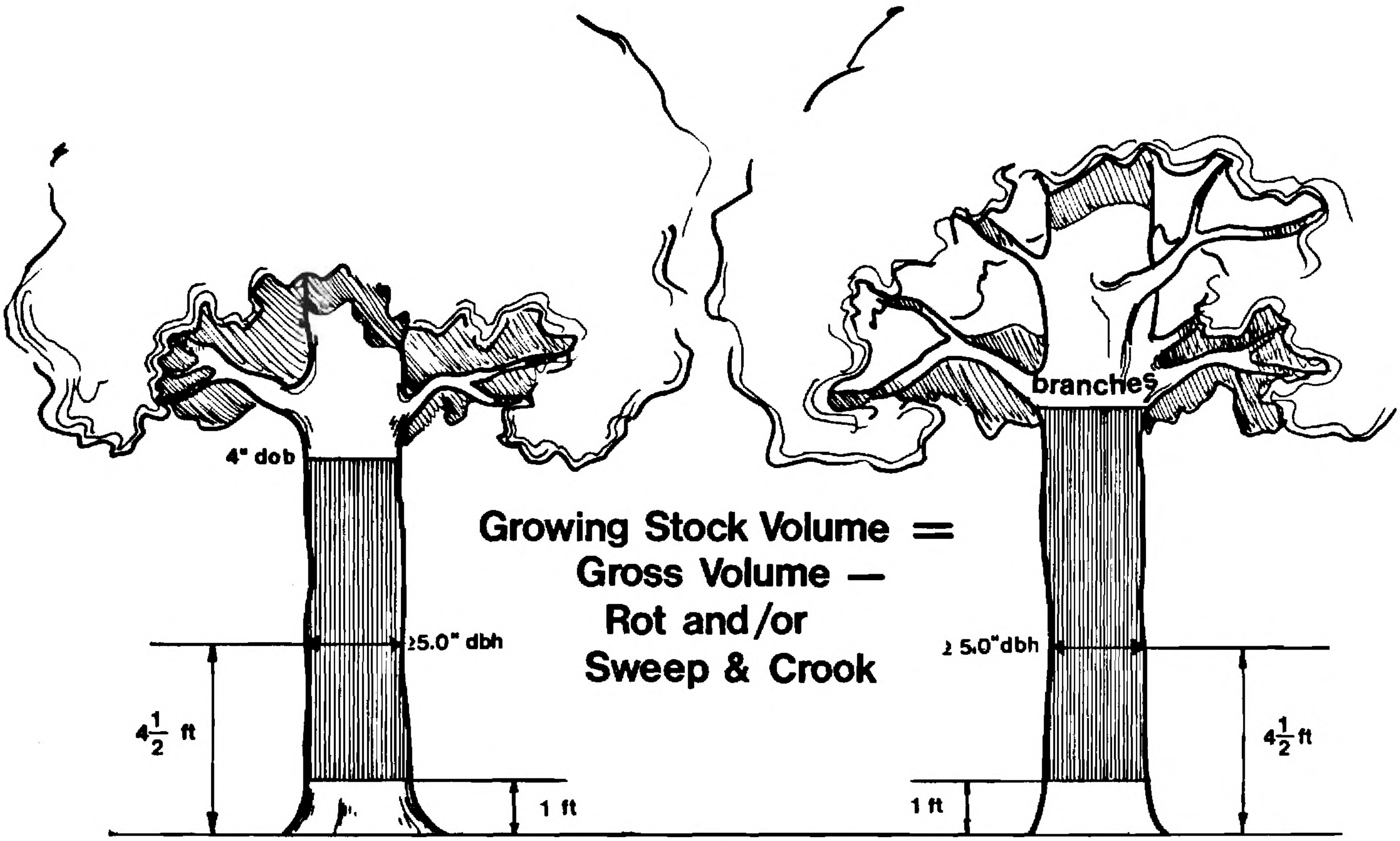


Figure III-5

USABLE PORTIONS OF TREES INVENTORIED
FOR WOOD PRODUCTS

Figure III-6

FOREST LAND AS A PERCENTAGE OF STATE LAND AREA
FOR THE UNITED STATES

The South is a major timber-producing region with 48 million acres of loblolly shortleaf pine and 69 million acres of oak-hickory systems. In 1976, the South grew over 6 billion cubic feet of softwoods and 4.5 billion cubic feet of hardwoods. The South's forest lands have the highest average potential for timber production of any section in the country.

Forests are the natural or climax vegetation on nearly all of the land in the Northeast. That is, without man's intervention much of the open land would revert to forest. Maple-beech-birch forest type covers over 20 million acres and contains some of the most valuable hardwood species such as sugar maple and yellow birch. However, most stands have been highgraded, resulting in an unnaturally high percentage of rough and rotten trees. Oak-hickory ecosystems comprise another 20 million acres in the Northeast. Included in this sytem are black walnuts, the most valuable native tree species in North America; white oak, important for cooperage and furniture; and yellow poplar, used extensively as veneer.

A major deterrent to management of oak-hickory forests has been the lack of adequate markets for low quality hardwoods. Productivity in the Northeast is more than 85 cubic feet per acre on one-third of the land and less than 50 cubic feet per acre on one-fourth of the land. The potential yields indicated by site productivity classes are generally not attained; only a small proportion of the land supports desirable trees of good form, vigor, and preferred species. However, under intensive management, the greater productivity could be achieved.

Forest Resources in West Virginia. Commercial forest area in West Virginia is 11.5 million acres or 75% of the total land area. Figure III-7 shows commercial forest land area as a percentage of total land area for each county in West Virginia. Oak-hickory is the principal forest type, and sawtimber stands account for just under half the commercial forest area.

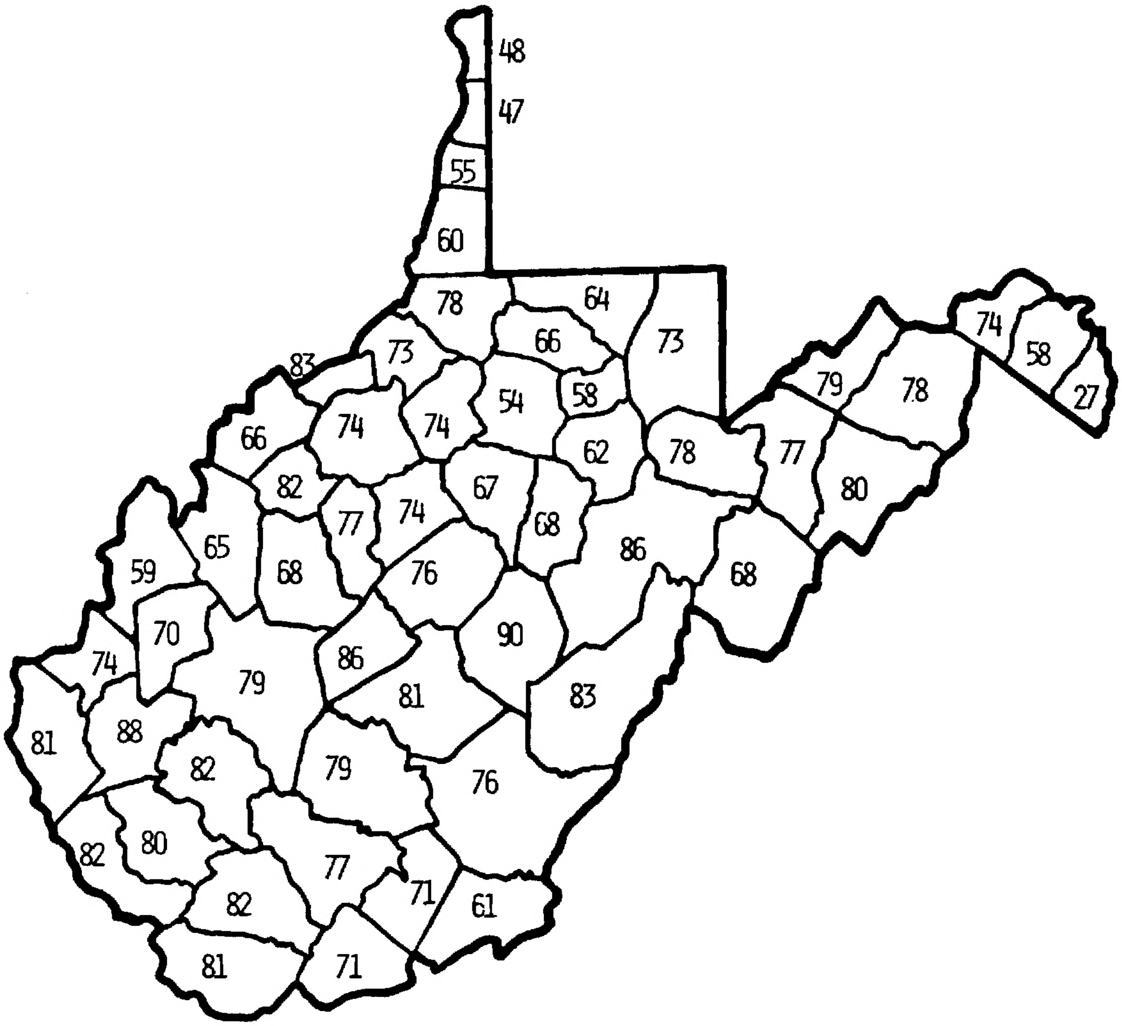


Figure III-7

COMMERCIAL FOREST LAND AREA AS A PERCENTAGE OF TOTAL LAND AREA FOR EACH COUNTY IN WEST VIRGINIA

While most forests in West Virginia are fully stocked with live trees, rough and rotten trees are a large enough component in half the stands to exclude them from the category of "fully stocked with growing stock trees." One out of four hardwoods and one out of eight softwoods are too crooked or rotten for lumber and veneer. This is partly why average annual growth per acre is 41 cubic feet, far below the potential 85 cubic feet or more that can be grown on 42% of the land and 50 cubic feet or more on another 40% of the land. Reducing the non-growing stock component and intensifying management could increase the productivity of West Virginia forest lands as well as provide wood for energy.

Using Forest Service data, a comparison of West Virginia with the United States as a whole shows how the forest resources of the state are underutilized. Table III-1 shows inventory (that is, volume of all standing timber) and annual volume (that is, volume produced by the standing timber each year). Annual energy wood is equal to annual growth minus timber removals plus mortality, logging residues, other removals, and rough and rotten annual growth.

Maximum Available Energy Wood Supply in West Virginia

Wood Supply for State. When forest lands in the United States are inventoried by the Forest Service, timber volumes are reported in traditional units of board feet and cubic feet and include only the bole of the tree. Wood for energy, on the other hand, is more conveniently expressed as weight like coal; also, bark and crooked portions of the tree as well as small diameter stock have as much energy content as the bole.

With increased interest in wood as a fuel, foresters recently have generated equations and tables to estimate biomass of trees. Estimates include weight of both wood and bark for trunk, limbs, branches, and twigs, but exclude roots, a 6-inch stump, and leaves.

Table III-1

INVENTORY AND ANNUAL VOLUME OF FOREST RESOURCES
IN UNITED STATES, NORTHEAST, AND WEST VIRGINIA
(in millions of cubic feet)

	United States	Northeast	West Virginia
INVENTORY			
Growing Stock	712,989	99,950	14,152
Rough	43,294	9,347	1,516
Rotten	23,545	5,146	640
TOTAL	779,828	114,443	16,308
ANNUAL VOLUME			
Growing Stock	21,874	3,184	488
Removals	- 14,425	- 1,302	- 167
Excess Growth	7,449	1,882	321
Mortality	4,035	696	66
Logging Residues	1,409	225	41
Other Removals	1,220	140	26
Rough and Rotten*	439	233	49
TOTAL ENERGY WOOD	14,552	3,176	503
UTILIZATION			
Removals to Growing Stock	66%	41%	34%

*Annual growth rate of rough assumed equal to growing stock rate; annual growth rate of rotten assumed one-third that of growing stock rate; removals for products accounted for.

Source: Forest Statistics of the U.S., 1977 Draft.

Raymond Sarles of the Northeastern Forest Experiment Station at Princeton, West Virginia, applied tree weight estimators to the latest forest inventory data for West Virginia to obtain tonnage of wood available for energy -- over and above the tonnage now harvested for other products.

The total amount of wood for energy from West Virginia's forests can be expressed as an equation:

$$\text{Energy wood} = (\text{Net growth} - \text{Timber cut}) + (\text{Mortality} + \text{Logging residue} + \text{Other removals})$$

Inventory volume tables were converted from cubic feet to tons for each component of the forest. Survey data include numbers of trees by species and diameter at breast height (dbh) size classes. Tree-weight equations and/or tabular values were applied to compute wood tonnages for species groups by dbh class. In this manner, inventory estimates in tons were obtained for growing stock trees, saplings, and rough and rotten trees by hardwoods and softwoods.

Annual tonnages were calculated by applying growth and mortality rates to the inventory data. Tonnages of harvested wood plus logging residues and other removals were determined by applying average cubic-foot weight factors for wood and bark of hardwoods and softwoods.

The results of Sarles' conversion of forest inventory data to weight (millions of tons) for West Virginia are summarized in Table III-2. Thus it was estimated that in 1974 the maximum weight of energy wood potentially available from the forests of West Virginia was 34.1 million tons.

Wood Supply by Units and Regions. From the estimated total annual wood theoretically available in the entire state of West Virginia, it was possible to estimate the proportion of this total that was theoretically available in each of West Virginia's Geographic Survey Units and in each of the state's Planning and Development Regions.

Table III-2

CONVERSION OF WEST VIRGINIA FOREST INVENTORY DATA TO WEIGHT, 1974

Total Inventory	981.0 million tons
Annual Growth	32.9
Annual Removals	- 6.2
Annual Mortality	+ 5.3
Annual Logging Residues and Other Removals	+ 2.1
ANNUAL ENERGY WOOD	34.1 million tons

First, portions of the state's total annual energy wood supply were allocated to each of the three Geographic Survey Units (see Figure III-8) as outlined below.

For net growth, mortality, and timber cut:

$$\text{UNIT WEIGHT} = \frac{\text{UNIT VOLUME}}{\text{STATE VOLUME}} \times \text{STATE WEIGHT}$$

where UNIT WEIGHT = Weight of energy wood per unit

UNIT VOLUME = Volume of wood per unit for each component (from Bones 1978)

STATE VOLUME = Volume of wood for the State for each component (from Bones 1978)

STATE WEIGHT = Sarles' weight of energy wood for the State

For annual logging residues plus other removals:

$$\text{UNIT WEIGHT} = \frac{\text{VOLUME OF STATE RESIDUES \& OTHER REMOVALS}}{\text{VOLUME OF TOTAL STATE TIMBER CUT}} \times \text{UNIT WEIGHT OF TIMBER CUT}$$

Saplings have no volume in Forest Survey tabulations; therefore, it was assumed that the sapling volume per unit is proportional to non-sapling volume. Rough and rotten volumes tabulated by the Forest Service for the units are total inventory rather than annual growth, so unit rough and rotten volume per year was assumed to be proportional to unit rough and rotten inventory.

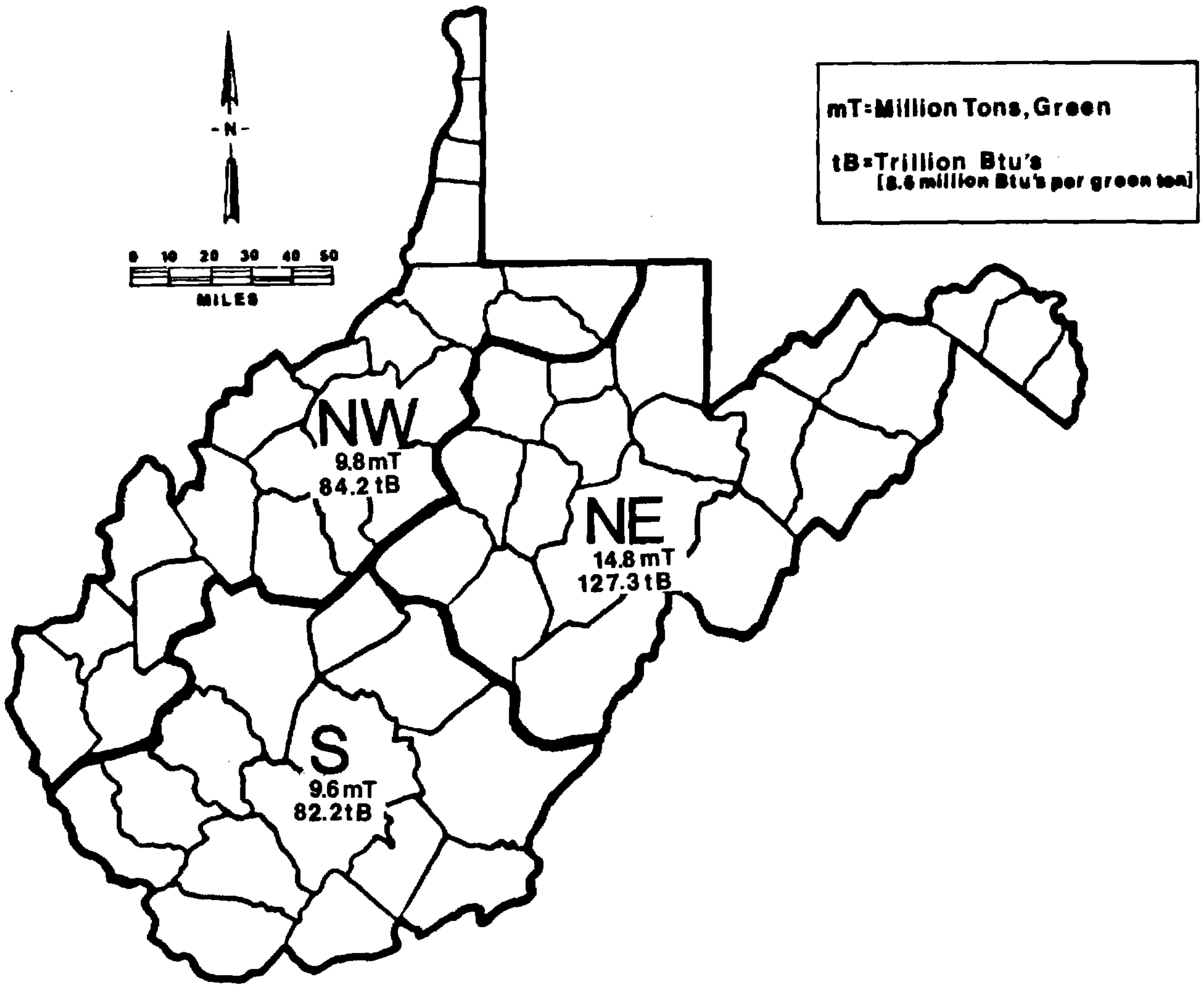


Figure III-8

THEORETICAL MAXIMUM ENERGY WOOD
PER YEAR IN WEST VIRGINIA
BY GEOGRAPHIC SURVEY UNITS

The Unit weights for energy wood components were then allocated to each of the 11 Planning and Development Regions set up by the West Virginia Regional Planning and Development Act of 1971 (see Figure III-9).

$$\text{REGION WEIGHT} = \text{UNIT WEIGHT} \times \frac{\text{REGION VOLUME}}{\text{UNIT VOLUME}}$$

where REGION WEIGHT = Weight of energy wood per Region

UNIT WEIGHT = Weight of energy wood per Survey Unit

REGION VOLUME = Net volume of growing stock per Region

UNIT VOLUME = Net volume of growing stock per Survey Unit

That is, growth, mortality, timber cut, residues, and removals for each Region were assumed to be proportional to the total amount of growing stock inventory volume in that Region. (Ratios for Regions that straddle two Survey Units were adjusted accordingly.)

The results of these calculations provide an approximation of the maximum energy wood supply in West Virginia by Geographic Survey Unit and by Planning and Development Region. These results are expressed in millions of tons on the maps identified as Figure III-8 and III-9. The tonnage figures also are converted to Btu's (at the rate of 8.6 million Btu's per green ton) to express the potential energy value of the forest resources.

Manufacturing Residues. Residues from primary wood manufacturing plants account for less than 1% of the available energy wood in West Virginia. Although 45 million cubic feet of residues were generated in 1974, most was recovered and used for fiber-product chips or fuel. Usage trends are shown in Figure III-10 along with distribution of the unused portion of residue by Survey Units.

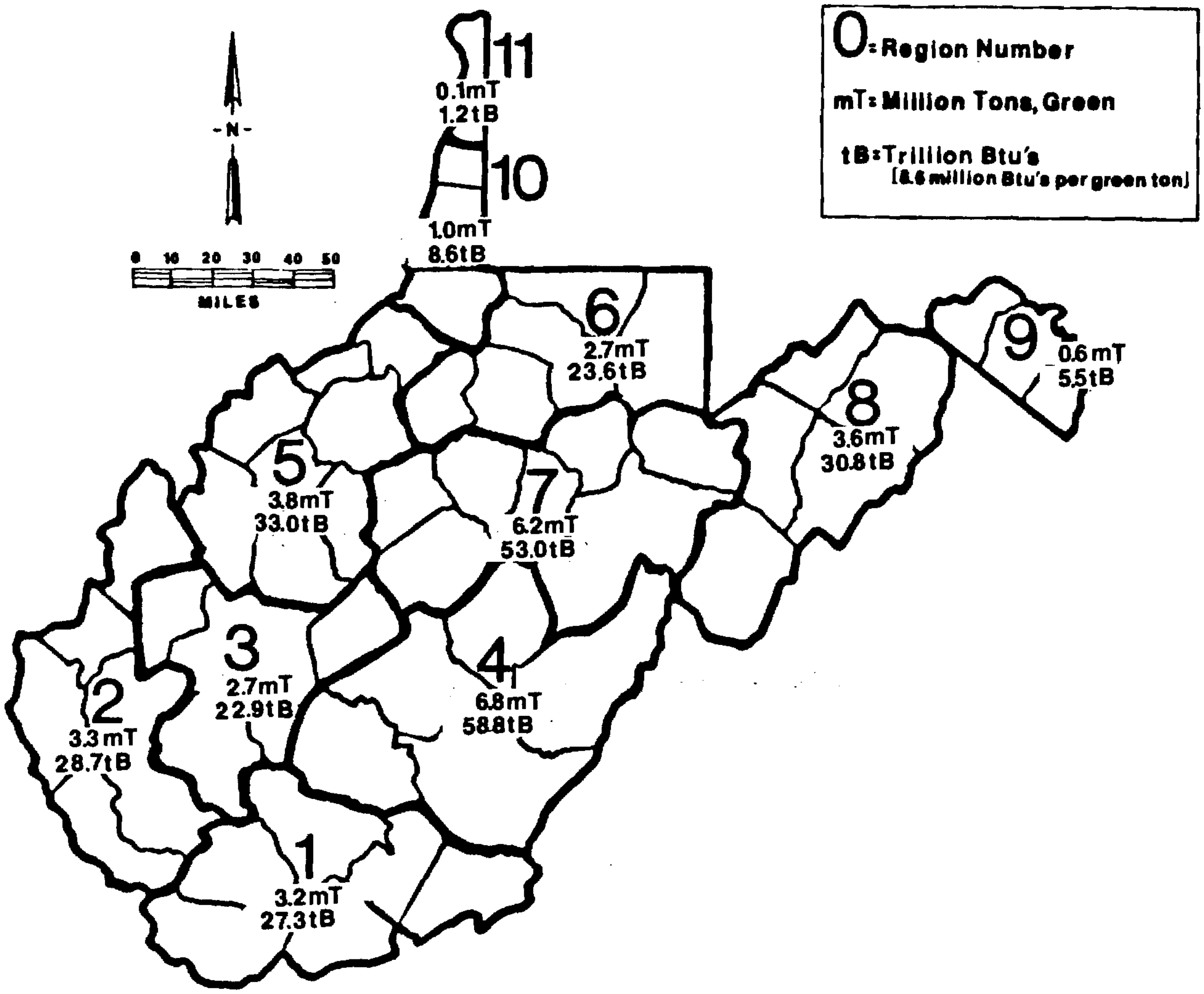
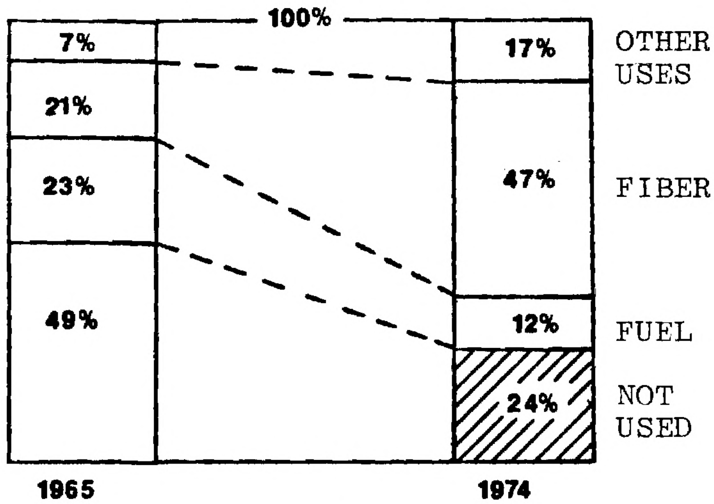
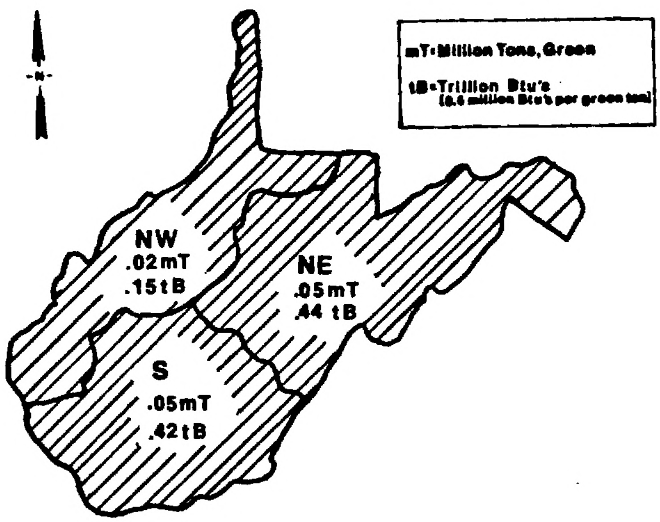


Figure III-9

THEORETICAL MAXIMUM ENERGY WOOD
PER YEAR IN WEST VIRGINIA
BY PLANNING AND DEVELOPMENT REGIONS



A. Trends in manufacturing residue use in West Virginia, 1965 and 1974



B. Allocation of Residue Not Used

Figure III-10

MANUFACTURING RESIDUES IN WEST VIRGINIA

Statewide, wood manufacturing residues are not significant; however, on a local level residues that are presently disposed of may provide an important source of low-cost energy.

Actual Energy Wood Supply Available in West Virginia

The determination of the West Virginia wood supply actually available for energy use was conducted in five steps:

1. Establish total acreage available for harvesting
2. Develop harvesting plan
3. Estimate the tons of wood per acre
4. Forecast pulpwood and lumber demand, and
5. Determine annual renewable fuelwood supply

West Virginia has 11,632,600 acres of forest land. Of this total, 148,900 acres are either unproductive or restricted, leaving 11,483,700 acres of commercial forest land. There are 68,400 acres of inaccessible land and 2,394,100 acres owned by people who do not intend to harvest wood. This leaves 9,021,200 acres of commercial forest land actually available for the production of wood.

A harvesting plan was designed to permit growth of shorter term pulpwood crops and longer-term lumber stands. Hardwood pulpwood is currently being cut at 30-year intervals in West Virginia, so this period was adopted for this study. Cutting time for lumber can vary widely, but 80 years was selected as a reasonable average.

Annual average growing stock net growth for West Virginia is 41.25 cubic feet of wood per acre. Using this growth rate and including tops, limbs, and small trees which are usually neglected, the material available for harvest is 69.3 and 184.8 tons per acre for 30- and 80-year cycles, respectively. The current state average is 85.4 tons per acre.

Assuming that pulpwood and lumber represent higher value uses and consequently will be supplied, these demands were forecast for 50 years. During this period, pulpwood demand is expected to increase 129% and lumber demand, 168%.

These facts result in 30 tracts of 32,467 acres for pulpwood growth and 80 tracts of 100,590 acres for lumber and other products. The pulpwood tract size was chosen to just meet the forecast demand in 2030. Using current and projected state levels, the graph in Figure III-11 was constructed. The demand for wood for other than energy uses will require just over half of the available resource.

Stumpage Prices Paid to Landowners

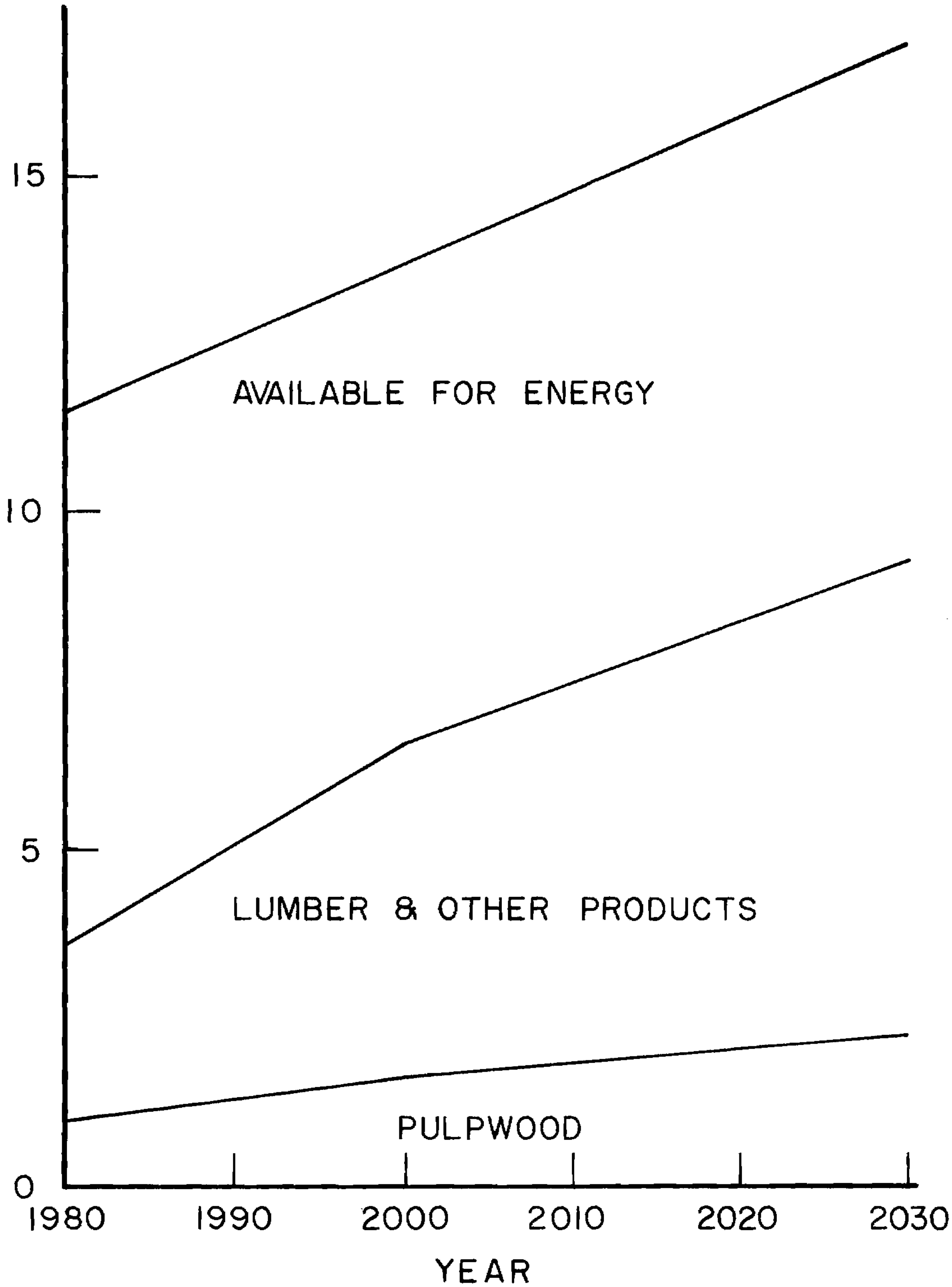
Because all of the wood being proposed as energy feedstock is currently unused or wasted, there is no price structure at present. Energy is a low-value use for wood, however, so wood costs can be approximated by looking at stumpage prices paid for higher-valued products. Table III-3 gives prices based on quarterly stumpage reports in West Virginia from May 1973 to December 1978. Wood for energy is therefore conservatively assumed to be worth $1.20 per ton.

Table III-3

STUMPAGE PRICES FOR SAWTIMBER AND PULPWOOD IN WEST VIRGINIA, 1973-1978

Type	Price per MBF	Price per Ton
SAWTIMBER		
Walnut	$535	$120
Mill Run	$50 to $100	$11 to $22
	Price per Cord	Price per Ton
PULPWOOD		
Softwood	$4.30	$2.10
Hardwood	$3.00	$1.20

FIGURE III-11
REALISTIC ENERGY WOOD SUPPLY IN WEST VIRGINIA



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IV. HARVESTING AND TRANSPORTING FUELWOOD

Introduction

Tree harvesting decisions can be categorized into two distinct areas: (1) the type of cutting procedure to utilize and (2) the type of equipment to use.

There are two general forms of cutting procedure -- clearcutting and selective cutting. Each technique has distinct advantages associated with its use, a few of which are:

Clearcutting

- Promotes the growth of intolerant tree species
- Improves the health of poor forests
- Provides more vegetation for wildlife
- Reduces setup cost for harvesting

Selective Cutting

- Promotes the growth of tolerant tree species
- Aesthetically pleasing to the layman
- Provides shelter for wildlife
- Maintains stable watershed

One important distinction between the two for West Virginia is the effect of each on shade intolerant tree species such as black walnut and black cherry. Selective cutting techniques which have been used in much of West Virginia have contributed to the near extinction of these valuable tree species in the state.

Equipment selection for harvesting in West Virginia is influenced by many factors, of which the steepness of the terrain is of key importance. The hills prevent the use of many types of mechanized and highly productive types of machinery which can be used on them. For approximately one-fifth of the state, however, the topography is relatively flat, and more conventional mechanized equipment can be used. Unfortunately, much of this flatness exists in valley bottoms strung out over great distances. Hence a typical West Virginia harvesting site would consist of a hillside operation and a valley bottom operation, each with its own equipment and productivity mix.

Finally, transporting fuelwood from the harvesting site to an industrial user will depend both on carrier rates and the number of cargo transfers required. For large transport, cargo transfers become a critical deterrent for certain end uses. Likewise, the location of sites in relation to rail spurs affect the advantage of rail versus truck hauling.

Harvesting Techniques

Harvesting is an integral part of silviculture, the cultivation of forests. It is a tool used in forest management that allows forests to be considered a renewable resource. In the early 1800's, forests were viewed as an obstacle which had to be cleared for farms, roads, and towns. In the latter part of the nineteenth century, loggers gleaned the best trees, leaving inferior and unhealthy species to take over the logged areas. Neither situation involved silvicultural harvesting because no thought was given to regenerating the forests.

Recreation, wildlife, watershed, and timber for products should not be sacrificed in harvesting wood for energy. And wood that is harvested now not only will be useful for energy, but also will increase the potential of the forestland for the future. Defective and poorly formed trees are a large component in 52% of West Virginia's commercial forest stands -- one in every four hardwood trees and one in every eight softwood trees. Using these low-value trees for fuel will make way for product quality trees that can boost the state's economy. Also, during the 60-year growth period, naturalists and recreationists can observe an increased variety of ecological systems as the forest stand matures.

Types of Stands

Stands in which all trees are approximately one age are known as "even-aged stands." A sprinkling of small diameter trees should not be misinterpreted as new reproduction or other age classes. Some trees grow more rapidly, causing others to be stunted from lack of sufficient nutrients and sunlight.

Even-aged stands found in nature are the result of fire, storm, or disease. Without these natural disasters, shade tolerant species such as beech and hemlock would eliminate the intolerant species that require large sunny forest openings for healthy reproduction. Black walnut, black cherry, and white birch are three of the more attractive trees in West Virginia forests that are intolerant. Modern fire prevention methods protect lives and property by halting fires as soon as they are noticed; but improved fire, disease, and insect controls tip the age-old natural balance away from intolerant species.

Uneven-aged stands contain at least three age classes intermingled on the same area. This is actually an intermediate stage of growth undisturbed by natural forces that would eventually end in a forest fire or other natural clearing event.

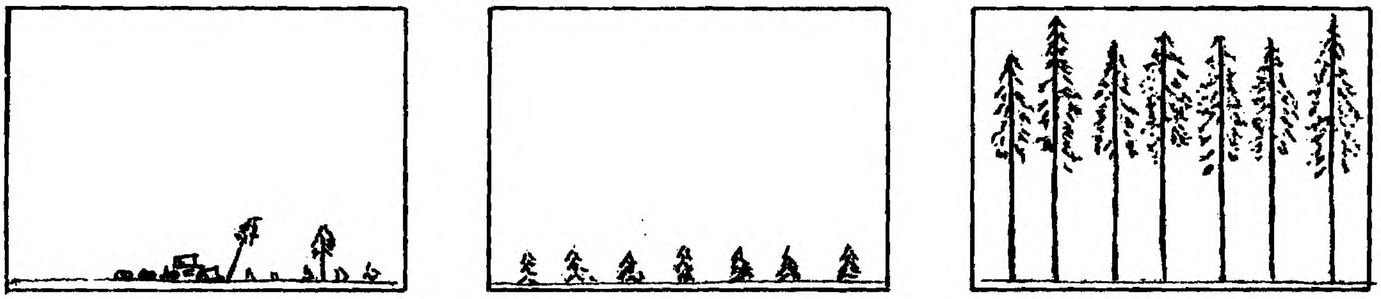
Harvesting Methods

Clearcutting. Forest management uses four basic harvesting methods to simulate nature in an orderly fashion.

In the clearcutting method, virtually all the trees are removed -- large and small alike. It is used when residual trees are not worth keeping for further increase in value, source of seed, protection of the new crop, or aesthetic value. Regeneration, accomplished by artificial or natural means, results in an even-aged stand. (See Figure IV-1.)

Figure IV-1

CLEARCUTTING METHOD OF TREE HARVESTING

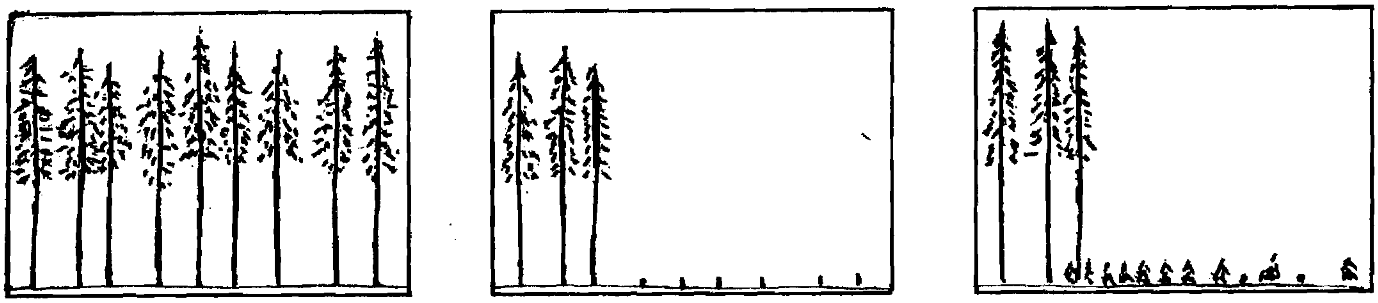


Clearcutting is best suited for growing intolerant species and those with relatively soft wood and weak root systems. It is especially applicable to eastern hardwoods as a health improvement technique for sections of forest in poor condition. Forests that have been highgraded can be clearcut so desirable species can grow once again. Clearcutting should be avoided on poor quality sites subject to erosion or on sites located within recreational areas.

Seed Tree. The seed tree method is similar to clearcutting; however, a few high quality trees are left standing to reseed the cleared area naturally. (See Figure IV-2.)

Figure IV-2

SEED TREE METHOD OF TREE HARVESTING

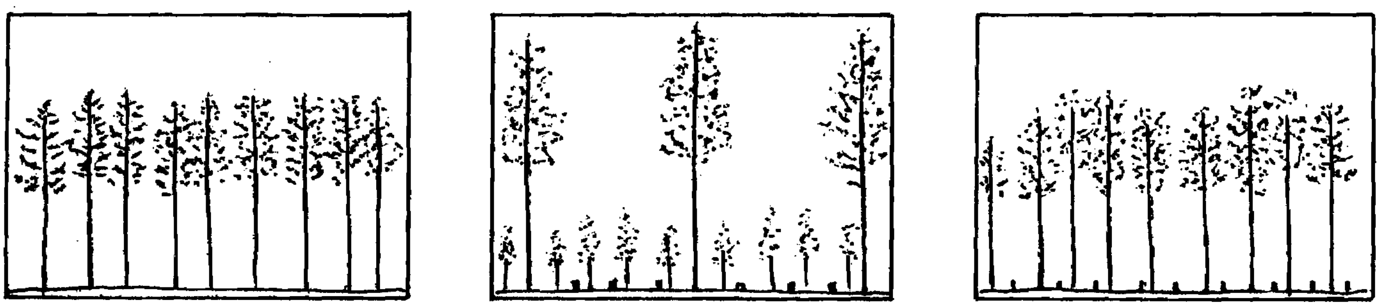


Some species do not bear enough seed to allow use of this method; others are not ecologically adapted to it.

Shelterwood. The shelterwood method involves a gradual removal of the entire stand in a series of partial cuttings that extend over a short period of time. Regeneration begins under a partial forest canopy and is released by a final cutting of the taller trees when the new crop requires full use of the growing space. (See Figure IV-3.)

Figure IV-3

SHELTERWOOD METHOD OF TREE HARVESTING

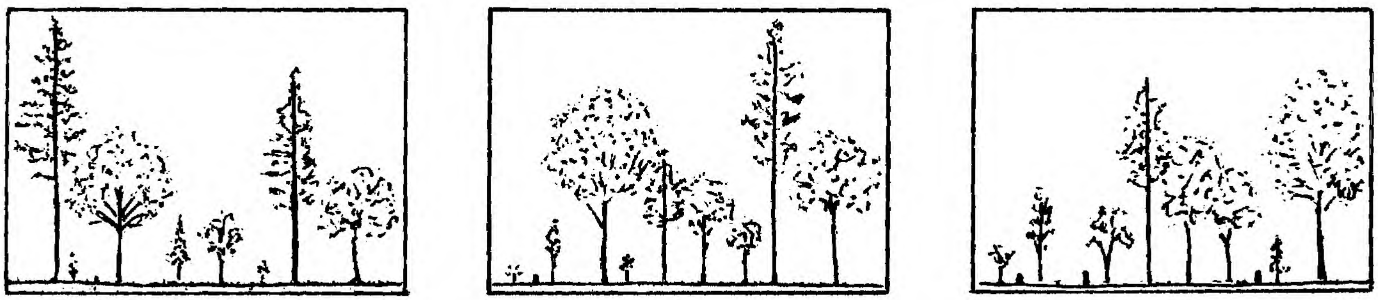


Although this method may be applied to all but the very intolerant species, it is most useful in reproducing those trees that require protection during the initial stages of development.

Selection. Only one silvicultural method results in uneven-aged stands, the selection method. (See Figure IV-4.) Mature timber is removed either as single scattered trees or in small groups at relatively short intervals. Such cuttings are continued indefinitely.

Figure IV-4

SELECTION METHOD OF TREE HARVESTING



Most uneven-aged stands are maintained that way because they are already in that condition and cannot be rendered even-aged without cutting too many young trees prematurely. It also may be that the desirable species reproduce and grow best or are least likely to suffer damage in the environment of an uneven-aged stand. The selection method provides a more aesthetic forest to the layman; however, the additional costs of logging under this method and the increased risk of damage to remaining trees make it uneconomical and unsuitable for fuelwood harvesting.

Harvesting affects the forest outwardly by determining the arrangement of the trees left standing and the new trees that appear. The choice of cutting method is determined by ecological and economic considerations. The felled trees can be used as wood for fuel; but what are the future plans for the stand? Choices should be made on the basis of species composition, age of trees, stand condition, soils, topography, microclimate, economics of harvesting, and objectives of management.

Economic considerations frequently encourage maintenance of nature's prescription of even-aged management. The most valuable species in any region tend to be relatively intolerant trees growing in even-aged stands. The risk of windfall dictates against uneven-aged management on exposed slopes or in shallow-rooted stands on wet soils. The principal disadvantage in clearcutting and seed tree methods is the potential marring of the scenery. Another criticism is that the even-aged stand does not offer as great resistance to injury from wind, snow, glaze, insects, and disease as does the uneven-aged stand.

Errors in application of harvesting methods have been committed and have touched off much controversy. In order to minimize errors in the future, the method best suited in a given area must be chosen.

Harvesting Equipment

The selection of timber harvesting equipment requires careful consideration of geological, environmental, and economic conditions.

Soil conditions, for example, play an important role in determining if equipment is suited for a job. Marshy areas require either high flotation or aerial equipment, and slippery hillsides usually require tracked equipment to scale them. In West Virginia in particular, steep hillsides with abundant rock outcrops (see Figure IV-5) or areas where soil conditions and steepness of grade pose a threat to landslides must be given special attention.

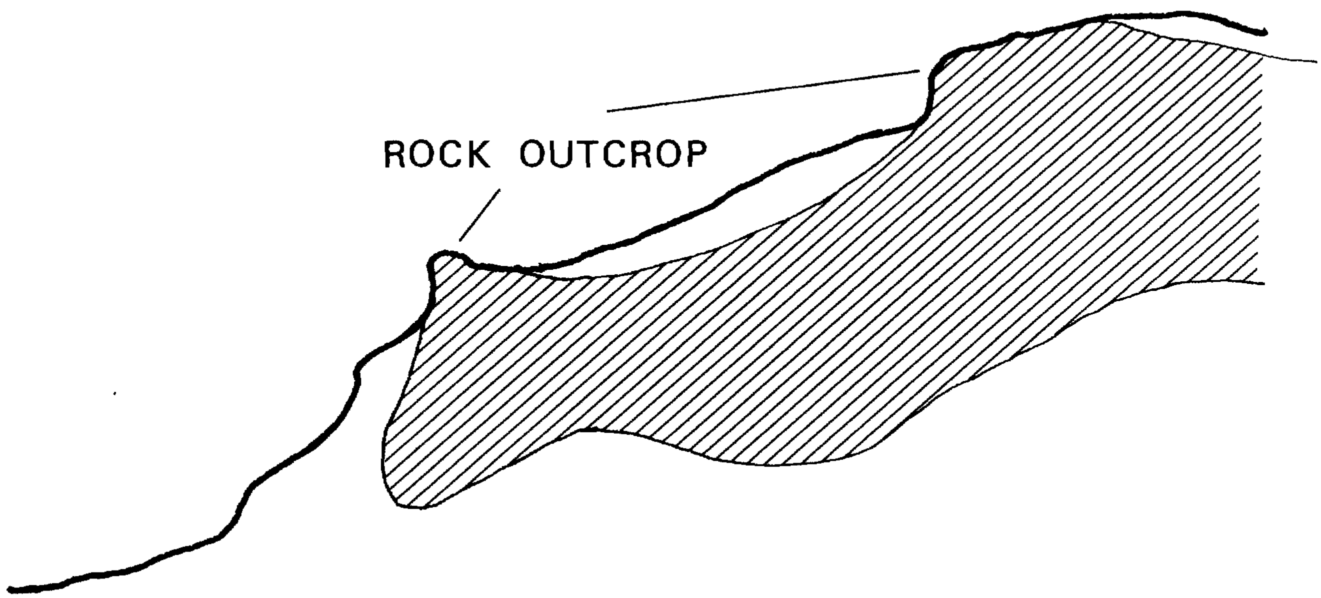
Of additional importance in selecting equipment for use in West Virginia is the degree of terrain slope. Approximately two-thirds of the state has a slope of 25% or better (see Figure IV-6), and even when the average grade is small local variances can be dangerous (see Figure IV-5). Consequently, many pieces of equipment that are well suited for flat terrain are not at all suited for West Virginia's hills. Examples include mechanical feller-bunchers and feller-forwarders, which risk tipover on grades above 35%, and rubber-tired skidders, which become unstable on grades above 40%. Certain retrievel systems are ideally suited for hilly terrain, but usually they are more expensive to operate than more conventional systems.

Environmental protection has become a watchword of the 70's, and timber harvesters are showing increasing awareness of the importance of taking precautions to preserve the original condition of areas being logged. Many aerial harvesting systems have been designed to yield very little disturbance to the area being logged. Likewise, procedures exist for properly building and maintaining logging road networks to limit environmental damage. However, the method of harvesting used can dictate equipment selection when the environment is considered. Clearcutting, for example, in certain areas necessitates cable or helicopter harvesting since exposed skid roads mar the landscape. Conversely, selective cutting can hamper the use of cable systems since many designs cannot be easily maneuvered around standing trees or leave damage to the residual stand.

Finally, productivity and cost must be considered in selecting equipment. Aerial systems can offer high

Figure IV-5

WEST VIRGINIA'S VARYING TOPOGRAPHY

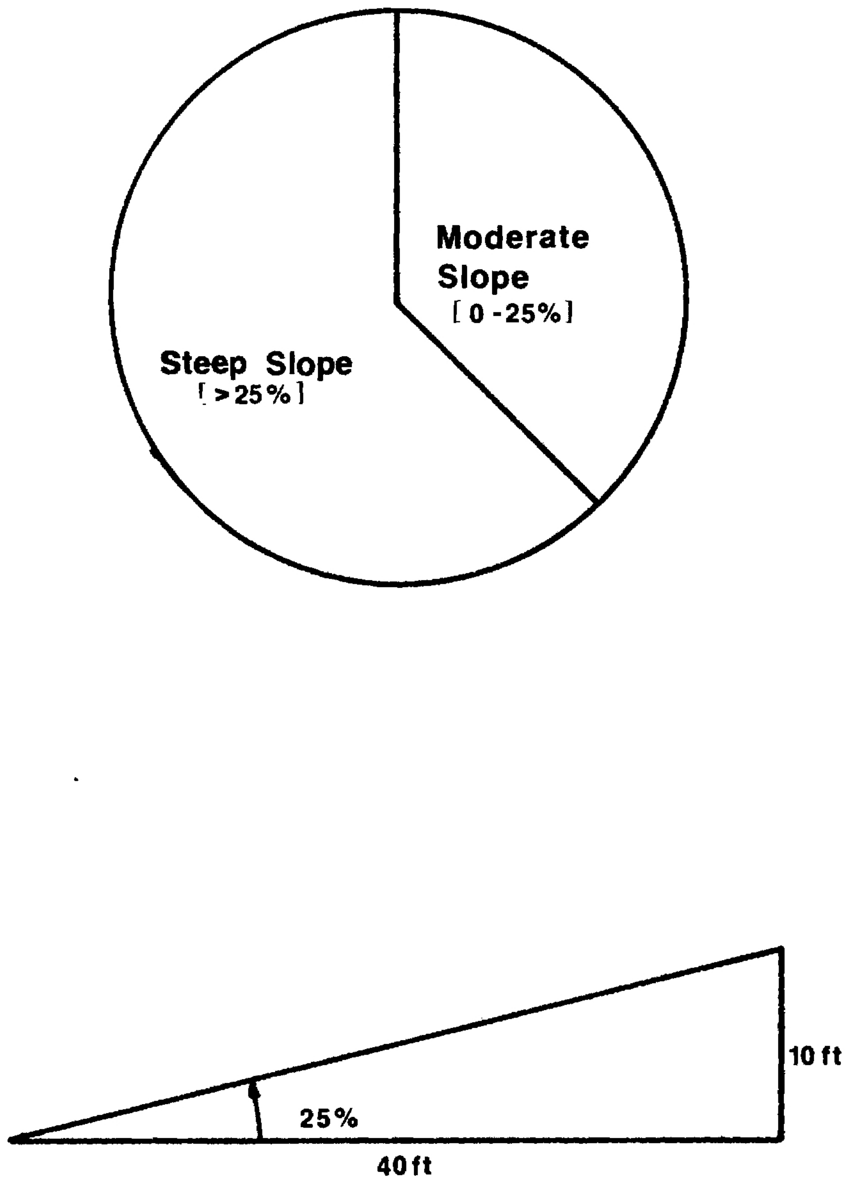


GEOLOGICAL CONDITIONS

SLOPE VARIANCE

Figure IV-6

WEST VIRGINIA SLOPE



productivity but usually at a high cost. A single skidding system, on the other hand, is usually less expensive than an aerial system, yet is also less productive.

Described below are the types of equipment available for use in timber harvesting operations in West Virginia. The equipment is categorized by that portion of the operation in which it is most often used:

- Felling
- Retrieval
- Loading
- Road Building and Maintenance

It is discussed also in terms of its suitability for use under specific conditions. Appendix C lists companies which supply each type of equipment.

Felling. Felling involves the actual cutting of the tree. In West Virginia most tree felling is currently accomplished with chain saws. These versatile tools are easily maneuvered on steep slopes and are much more productive than more conventional hand tools, such as axes and saws. While use of highly mechanized equipment in the felling process in West Virginia has occurred, this usage has been limited by the lack of stability exhibited by current mechanical feller designs on moderate to steep slopes.

- Chain Saws - Chain saws are rated on the basis of engine displacement. One and one-half to three cubic inch displacement saws are suited for limbing and intermittent use in cutting small timber. Three to four cubic inch displacement models are suited for cutting pulpwood and small sawlogs, particularly softwoods. Four to five cubic inch displacement models are the most common size used by commercial timbermen in eastern hardwood stands (see Figure IV-7). Saws with engine displacement over five cubic inches are suited for bigger timber generally found in the West. There are currently at least 30 different makes or brands of chain saws available on the U. S. market.

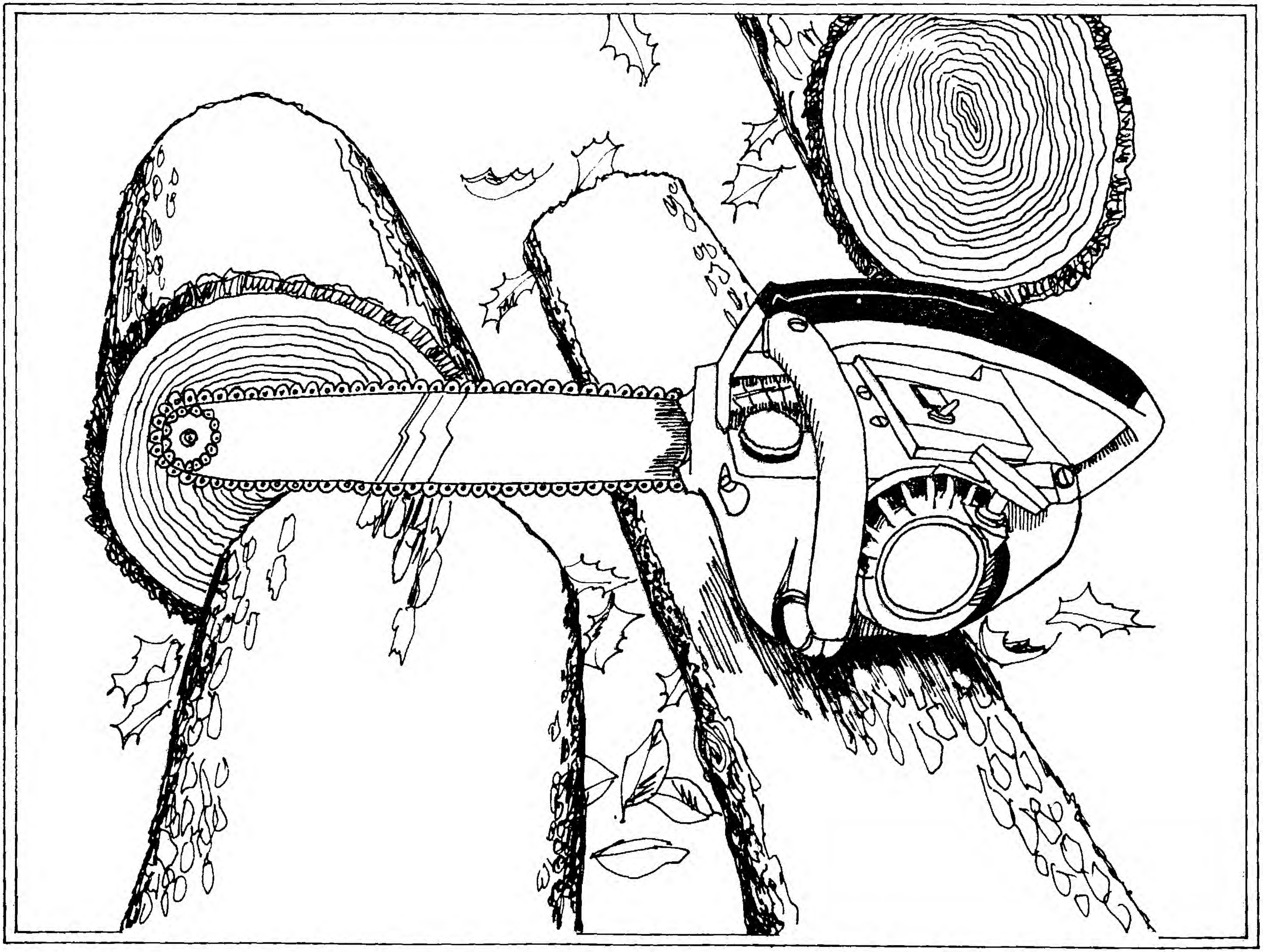


Figure IV-7. CHAIN SAW

Most are light, inexpensive machines of limited capacity built primarily for the occasional user. Commercial wood cutters use only about a dozen models built specifically for professional use. About half of these special tools are of foreign manufacture, most of which come from either Scandanavia or West Germany. They typically cost from $250 to $500.

- Fellers - Mechanical fellers are offered both as attachments for specific equipment or as an integrally designed self-contained system. Many can be acquired with accumulator arms for gathering several felled trees to stack into a pile. This type of unit is termed a feller-buncher. Other systems contain a hauling bed for transporting trees from the forest without dragging them on the ground. This type of system is termed a feller-forwarder. Due to the wide variety of designs available, they can cost anywhere from $40,000 to $110,000.

  Most mechanical fellers use the shearing action of two hydraulically actuated scissor-type blades. The largest shears can usually cut hardwoods up to 20 inches in diameter. Some newer designs combine chain saws or routers with the shearing action, but these innovations are primarily intended to limit sawtimber damage typically caused to the tree trunk by shearing.

  Since mechanical fellers are typically mounted on front-end or skidsteer loaders (see Figure IV-8), their stability on steep slopes can be dictated by the stability of the mount. U.S. Forest Service studies have shown that most logging tractors become unstable on grades between 20° and 35°, depending on their center of gravity. Consequently, mechanical felling in much of West Virginia is dangerous if not impossible since local topography often exceeds this range.

Retrieval. Retrieval is the removal of felled timber from the field to a central landing. Tree retrieval can be accomplished either by ground or aerial timber travel. Roads are built on steep slopes for most ground systems; however, certain geological conditions, such as rock outcrops or unstable soil conditions, can prevent the development of a road in certain areas. To date, skidding is the predominant form

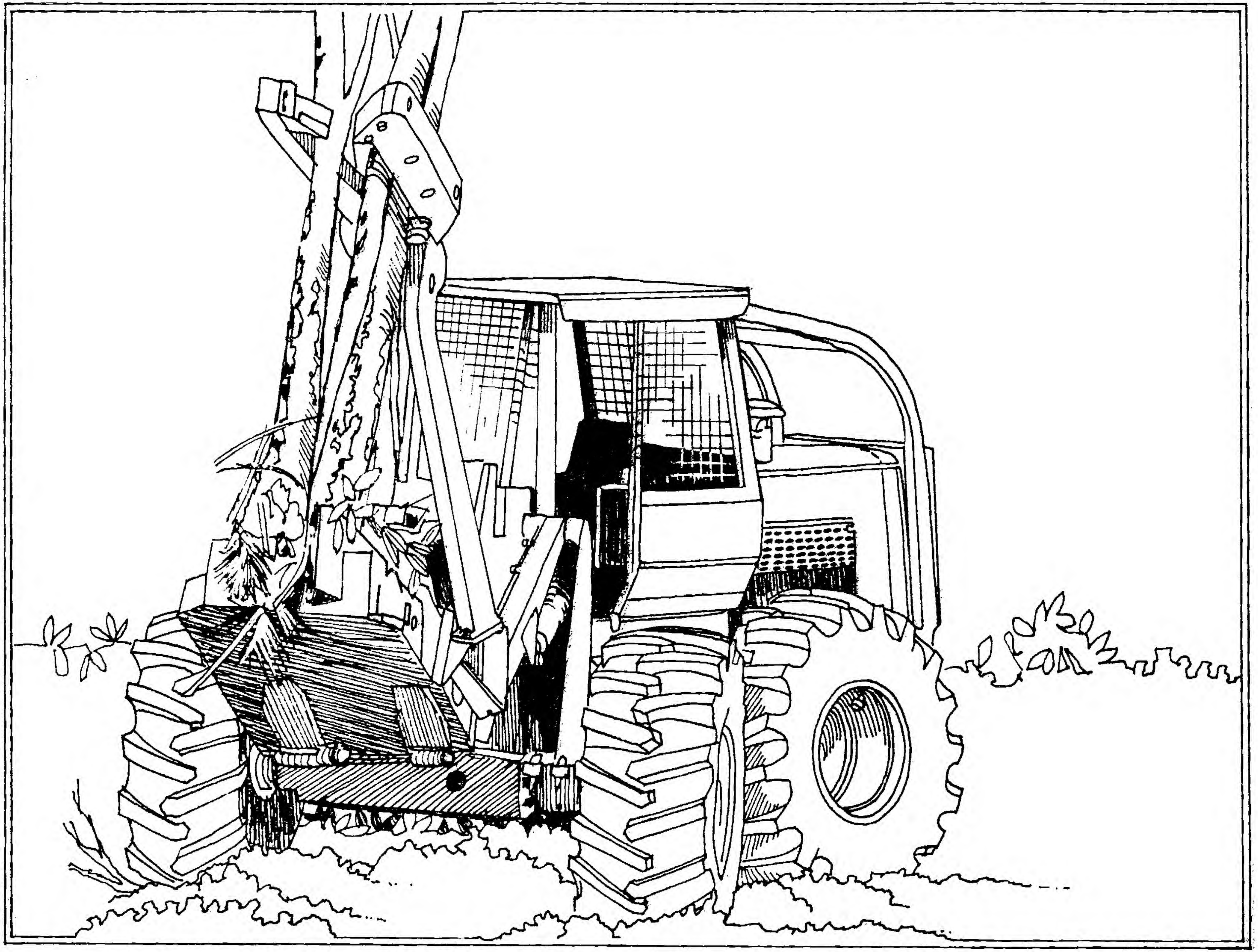


Figure IV-8. FELLER-BUNCHER

of retrieval utilized in West Virginia. However, increased interest is being shown in helicopter and cable harvesting systems, particularly as concern over higher productivity and reduced environmental damage increases.

- Skidders - The majority of tree-retrieval skidding performed in West Virginia is done with crawler tractors (see Figure IV-9). The crawler tractor generally leaves the sloped skid trail in better condition than rubber-tired units (see Figure IV-10), has a lower center of gravity for improved stability on the sloped trail, and can double as an earthmover in skid-road construction and maintenance.

  The typical skidder used in eastern woods is approximately 100 horsepower, weighs five tons, and can handle about one cord of tree length pulpwood or 500 board feet equivalent hardwood logs. An average skidding distance is about 1/8 mile, although runs of up to 1/2 mile are not uncommon.

  On steep slopes, trees are usually pulled to the skidder by cable winches mounted on the rear of the tractor. This allows timber retrieval over distances as great as 150 feet from the skidder, reducing the number of skid trails needed to harvest a stand. While grapple arms are available for mounting on the rear of skidders and are used quite often on flatter terrain, the use of grapples on steep slopes is impractical since the skidder must be backed over the log for pickup, a feat which jeopardizes the skidder's stability if it must leave the skid trail. Skidders can cost between $35,000 and $95,000, depending on the size and power selected.

- Forwarders - Forwarders are four-wheel-drive, rubber-tired skidders equipped with a bed on the back end to carry a load of logs completely up off of the ground (see Figure IV-11). A forwarder can travel at considerably higher speeds than can a skidder of comparable size. Therefore, the forwarder is useful in retrieving over greater distances than the skidder. Since the trees are carried off of the ground, forwarders also reduce the amount of grit and dirt which accumulate on timber during retrieval.

  Like rubber-tired skidders, forwarders are not commonly used in West Virginia for tree retrieval,

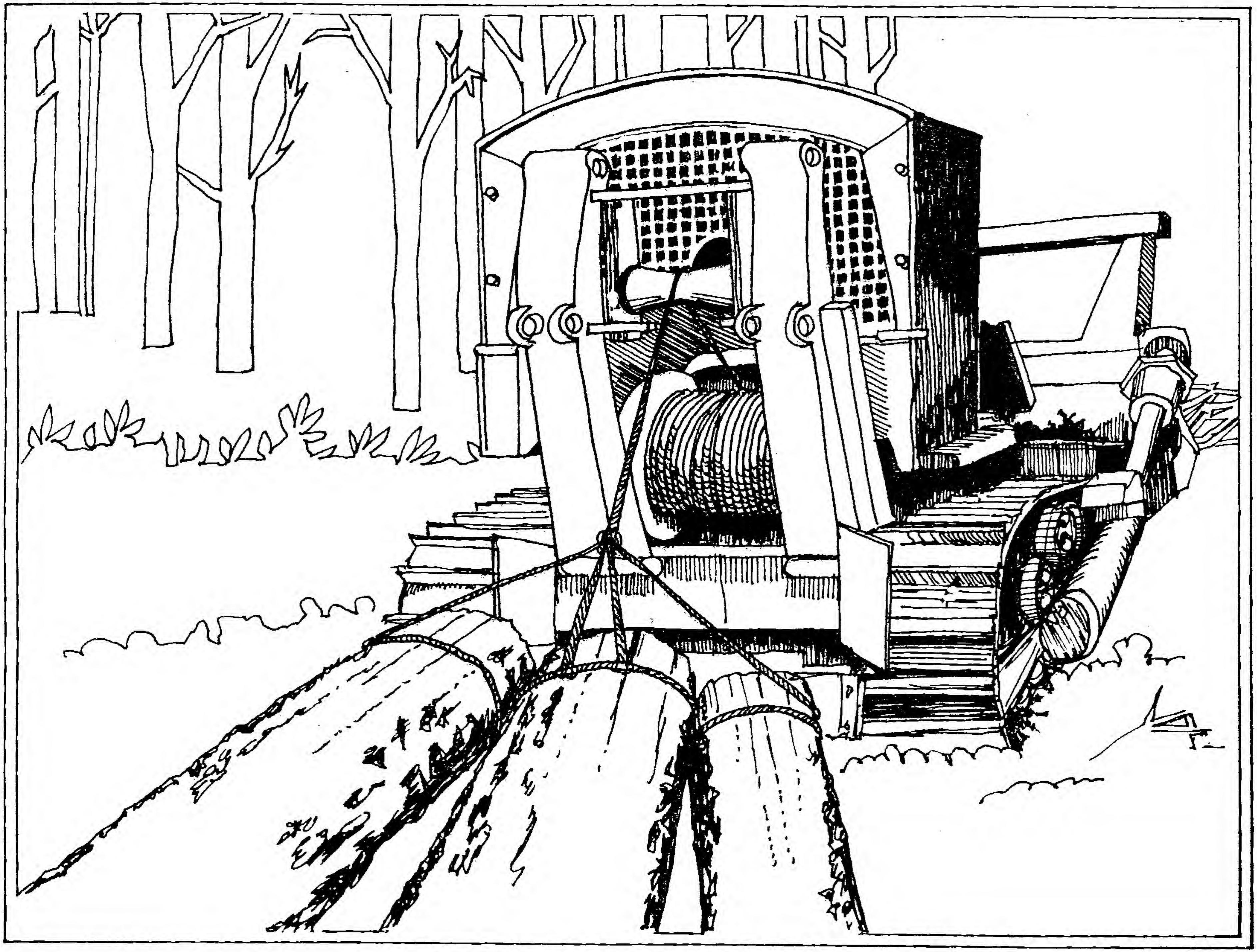


Figure IV-9. CRAWLER SKIDDER

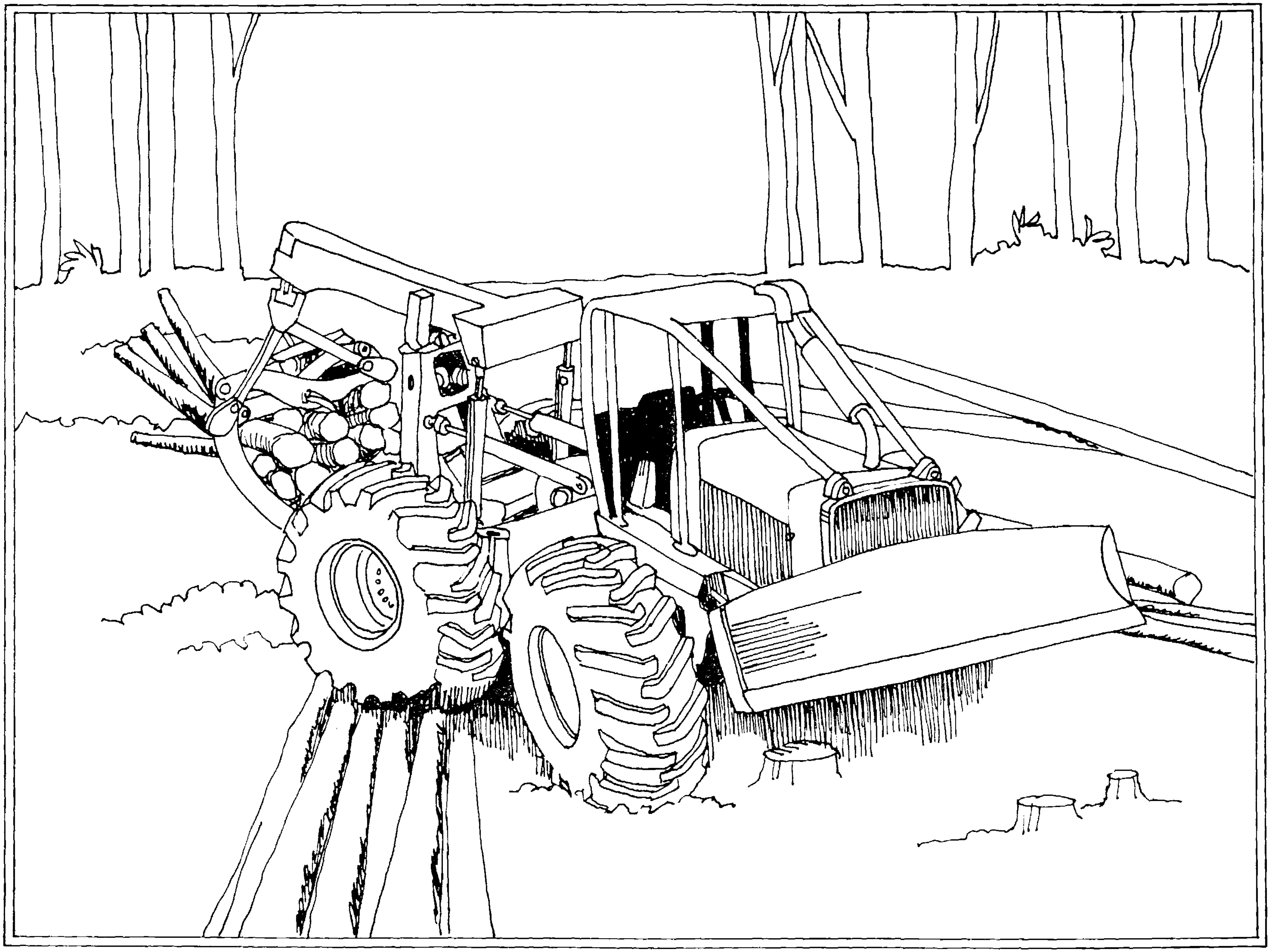


Figure IV-10. WHEELED SKIDDER

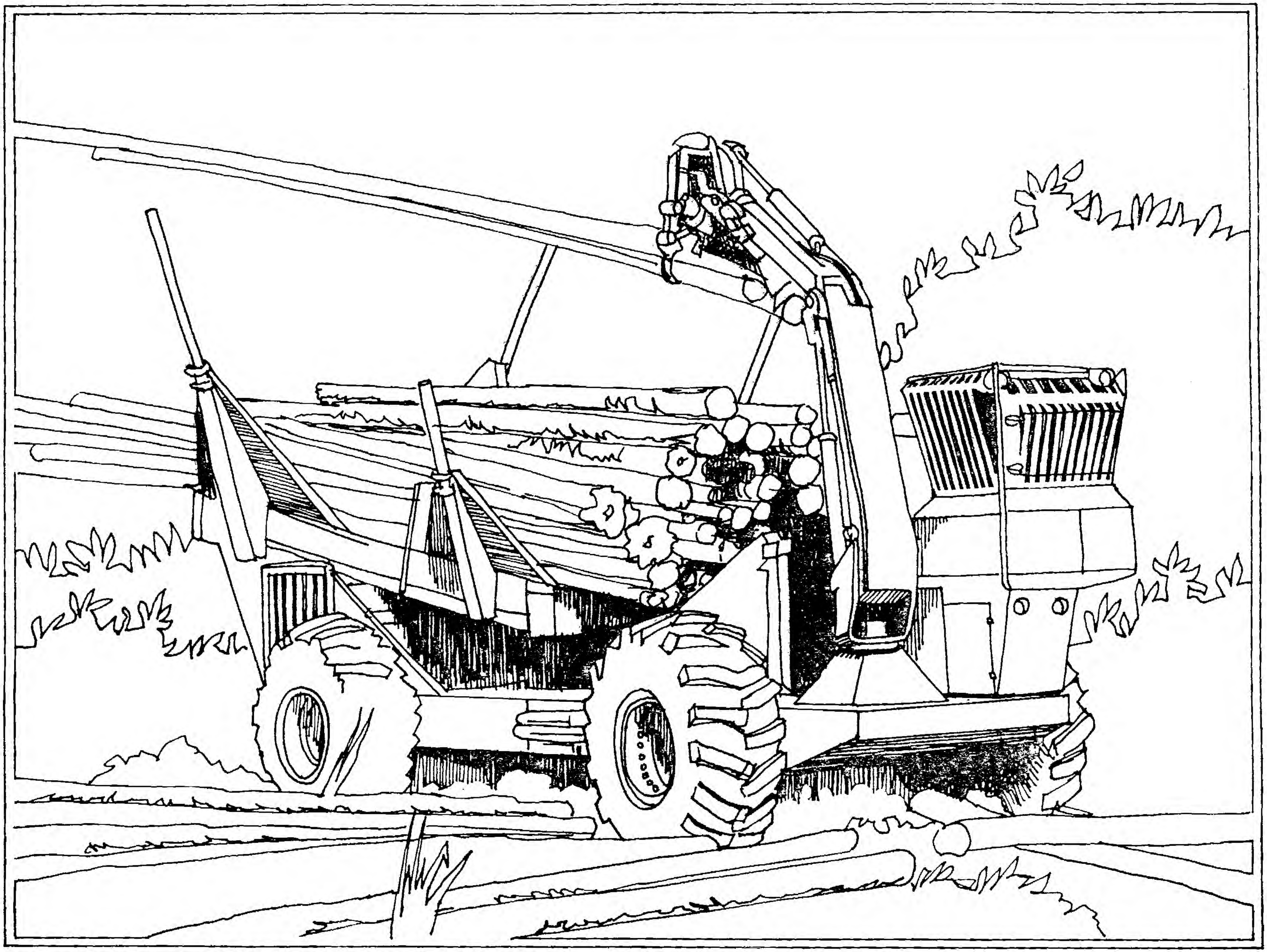


Figure IV-11. FORWARDER

because of their instability on steep slopes and potential damage to the sloped trail. A forwarder requires a better road than a skidder to operate at maximum efficiency, but does not need as good a road as a truck. Consequently, forwarders can serve to retrieve timber from remote areas to a centrally located truck landing, thereby reducing the number of truck roads needed.

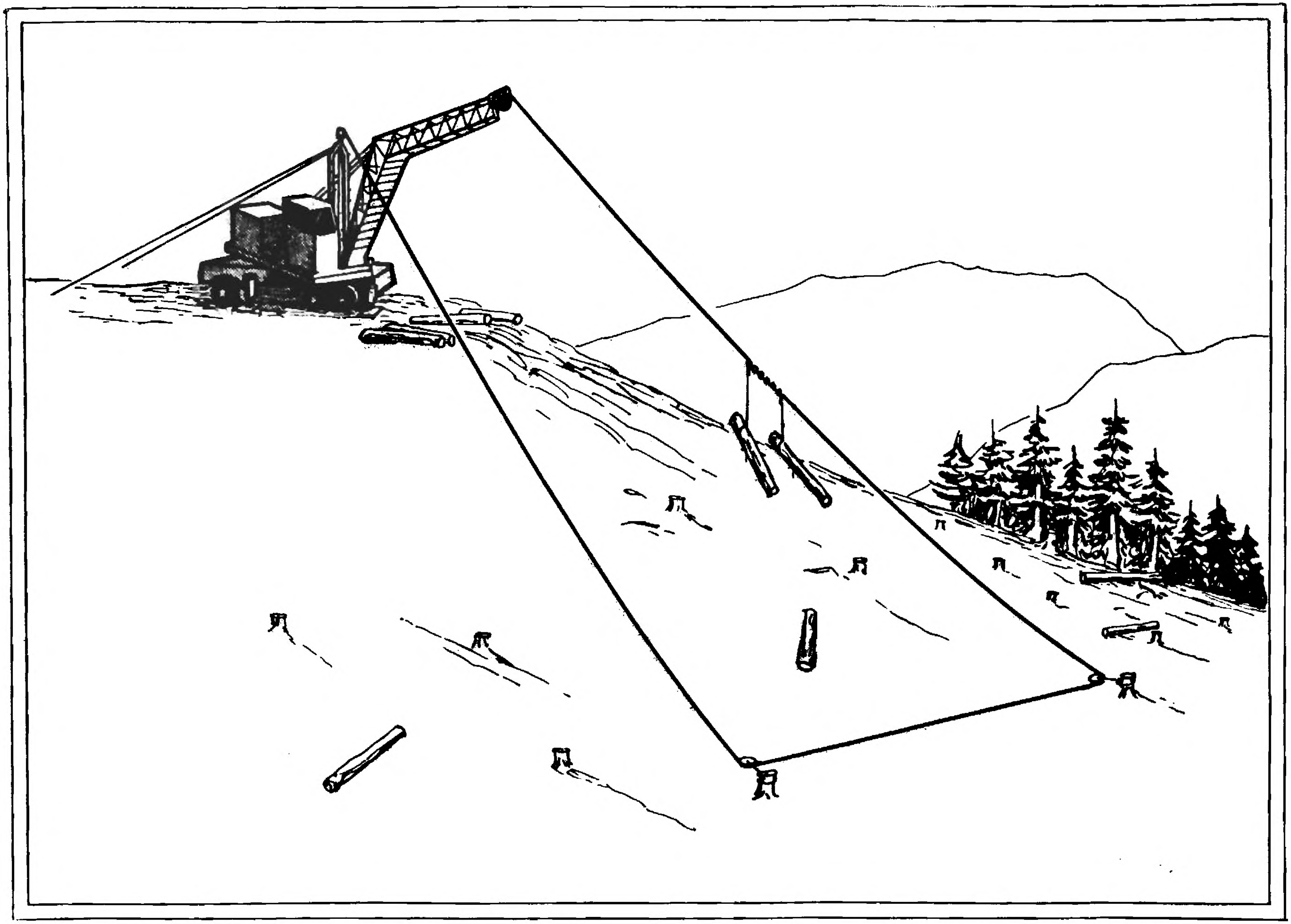
Most forwarders come equipped with a grapple mounted on a hydraulic boom to load their cargo. This design severely limits the maximum distance the unit can pull in fallen timber to the road, often necessitating numerous roads on steep slopes to effectively remove fallen timber. They can cost anywhere from $90,000 to $300,000.

- Cable Yarder - Primarily because of the environmental and aesthetic questions posed by skidding, cable systems are becoming of increased interest to Appalachian timber firms. These systems require fewer roads than skidders; therefore, the potential damage to the harvested area is less severe. Cable yarding systems range from small homemade wooden-boom jammers to large complex skyline towers. Most are fairly large in design, intended for use on large western timber on steep concave slopes. However, several designs have proven useful on eastern, second growth, hardwood timber on convex slopes. Such designs range in cost from $3,000 to $150,000.

  Cable yarders are classified according to their configuration. The most common classifications are: ground lead, live skyline, standing skyline, and running skyline.

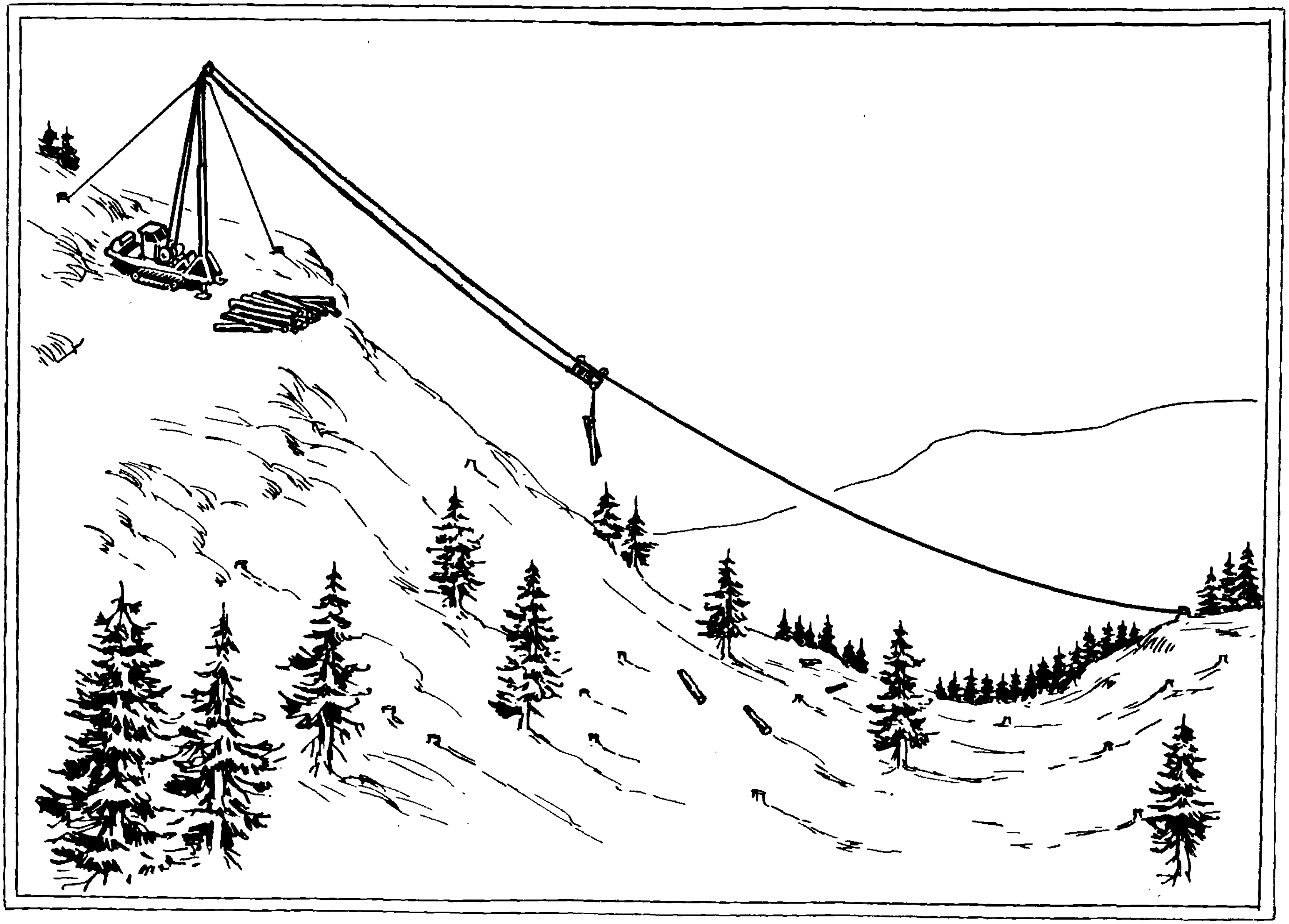
  Ground lead systems, unlike skyline systems, consist of a single tower and a single cable (see Figure IV-12). As implied, ground lead systems drag timber at least a portion of the retrieval distance; consequently, overall retrieval distances by these systems are usually limited to from 450 to 1,000 feet.

  Skyline systems, on the other hand, consist of one or more towers and two or more cables. A live skyline entails a system whereby a carriage is lowered by gravity along a main cable line to a spot where timber is to be retrieved. There, the main cable line is then lowered to allow the choker on the carriage to be attached to the timber (see Figure IV-13) and raised again for timber transport. A standing



(Drawing Courtesy of U.S. Forest Service)

Fig IV-12 GROUND LEAD CABLE YARDER



(Drawing Courtesy of U.S. Forest Service)

Fig IV-13 LIVE SKYLINE CABLE YARDER

skyline is similar to the live skyline except the main cable is fixed in place. The carriage travels, again by gravity, to the timber, where the choker on the carriage is lowered from the carriage to pick up the timber, then raised for transport (see Figure IV-14). Finally, the running skyline is similar to the standing skyline except that the carriage is pulled in either direction along the main cable instead of using gravity (see Figure IV-15). Since skylines usually carry their load off of the ground, they are able to retrieve timber over distances of from 500 to 4,000 feet.

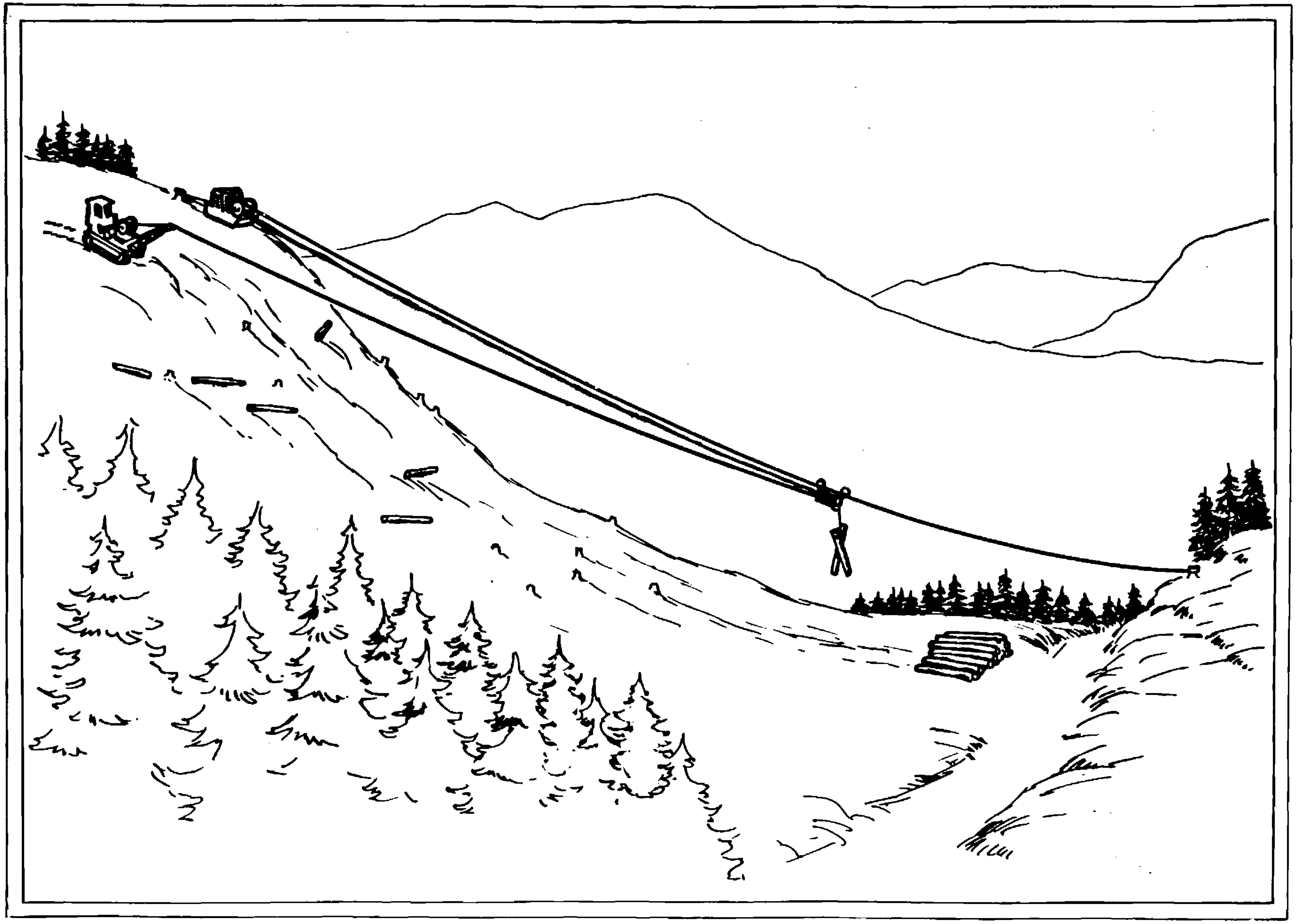
While most cable systems are designed for use in clearcutting operations, a few can be effectively used in selective cutting operations. A key ingredient in determining suitability for use in selective cutting is maneuverability around existing trees. In West Virginia, with its convex slopes, this becomes particularly difficult, since cables often fail to clear the tops of stand trees, complicating cable repositioning.

The U.S. Forest Service is experimenting with an inexpensive, ground level, standing skyline intended for use in selective cutting operations. The system is called the "Chuball" and consists of a weighted ball which moves up and down a guide wire, rolling down the hill to the felled tree, then being pulled up the hill holding the felled tree's trunk off of the ground.

Another system undergoing analysis by the U.S. Forest Service is also a standing skyline called the "URUS." The URUS was developed in Europe and appears to be practical in retrieving small hardwood trees on steep slopes. Due to the amount of setup effort needed, the system appears to be practical only on clearcutting operations.

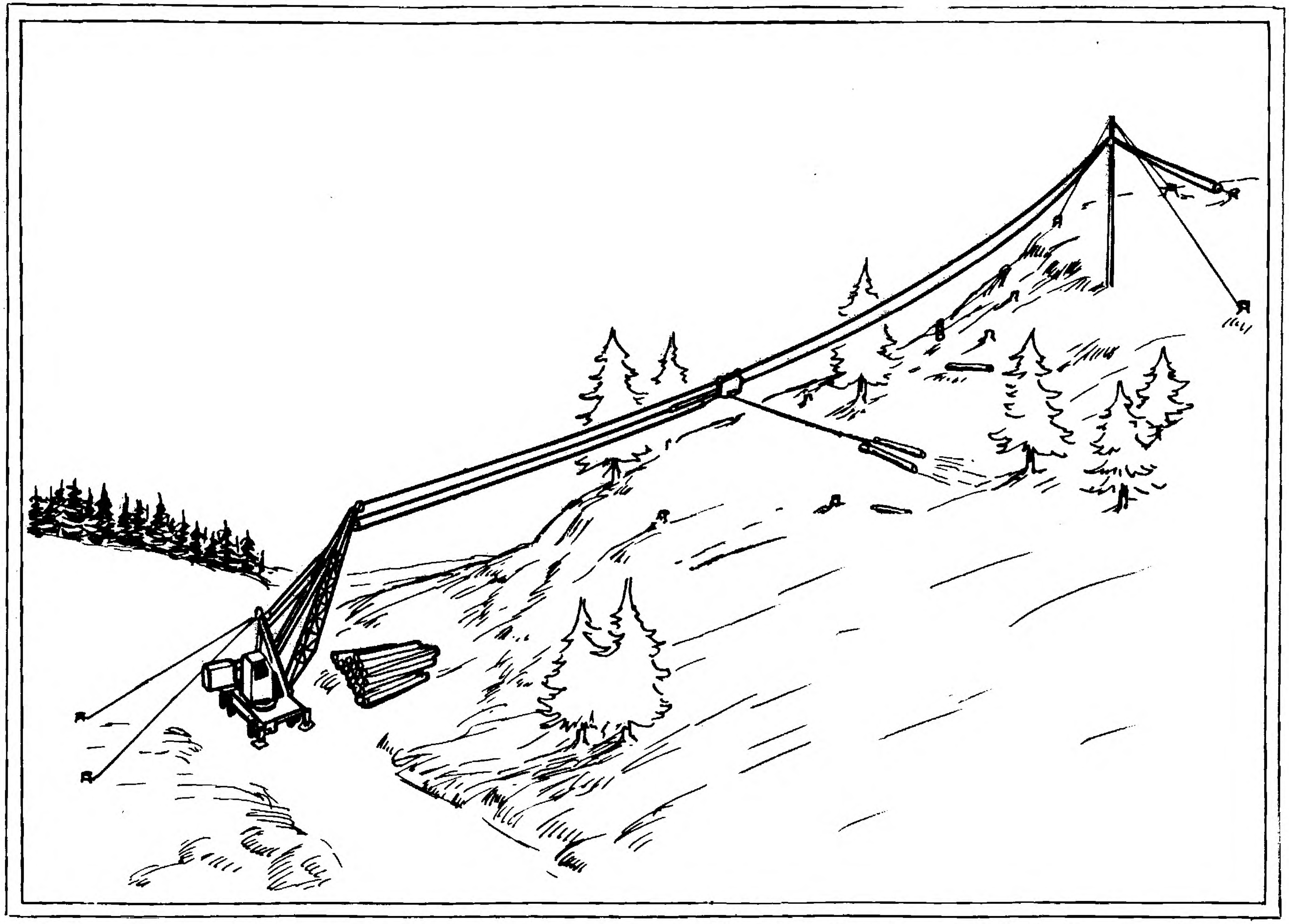
Finally, a third cable system which is in commercial use in eastern West Virginia is a running skyline system called a "Skylok 78." It is used to clearcut 20 to 40 acres of land for whole-tree chipping and has proven especially effective in clearcutting operations using a bulldozer as the tailspar, which can be easily repositioned.

While no one cable system has proven superior on West Virginia topography, running skyline systems do have



(Drawing Courtesy of U.S. Forest Service)

Fig IV-14 STANDING SKYLINE CABLE YARDER



(Drawing Courtesy of U.S. Forest Service)

Fig IV-15 RUNNING SKYLINE CABLE YARDER

an edge in that they do not readily get hung up on brush or the ground, if contact is made while being dispatched to the timber. Techniques such as the "Chuball" may help gravity-fed systems to overcome this drawback.

- Balloons - Balloon harvesting is actually a variation of cable harvesting. The twist is that a helium balloon is used to give the retrieved load the necessary lift to clear ground obstructions (see Figure IV-16).

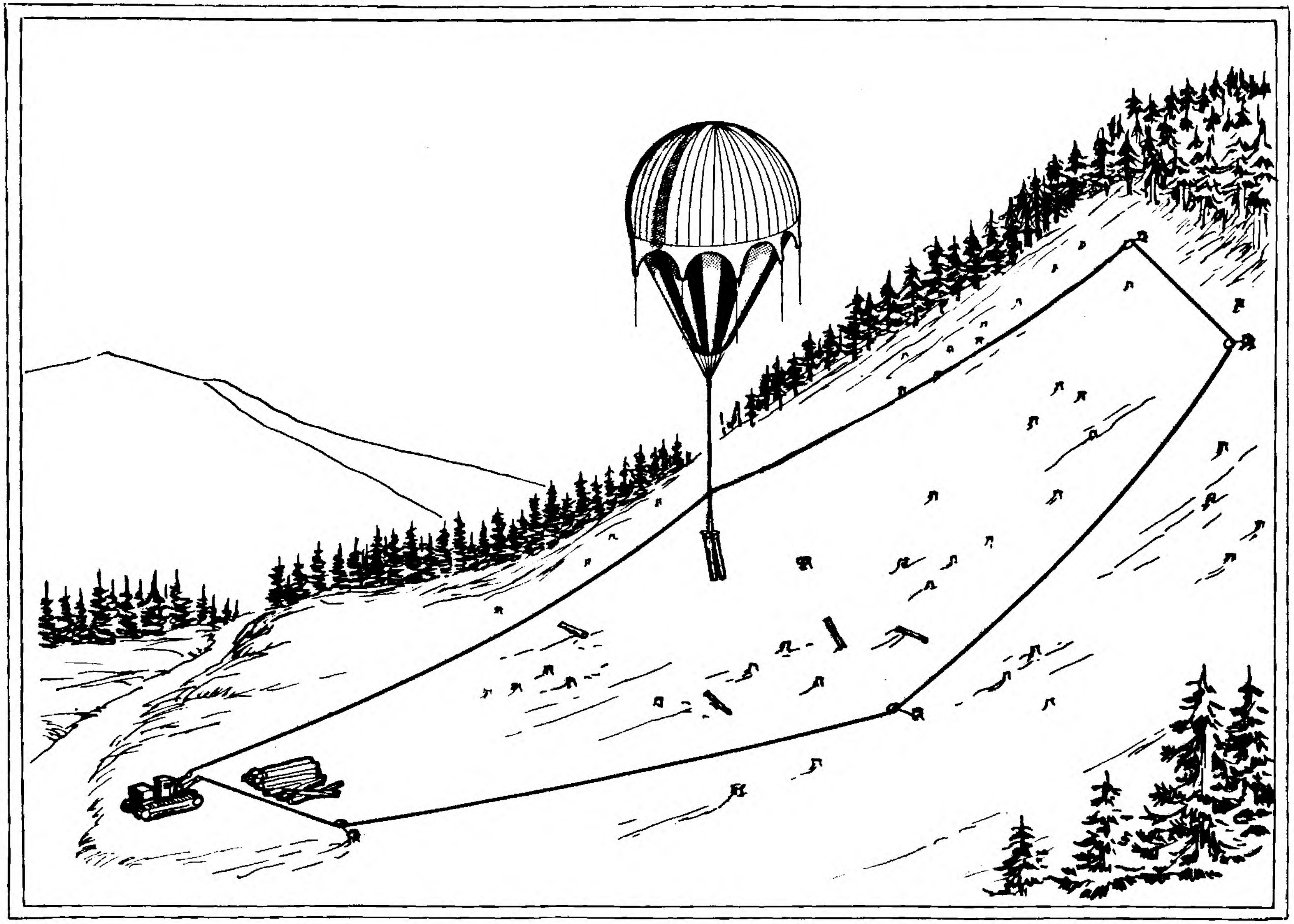
  Ballooning is suited for use on convex slopes and is capable of retrieving timber over distances of up to 4,000 feet. However, wind, rain, and snow can hamper the balloon system's effectiveness in lifting and carrying timber. Ballooning has proven effective primarily in clearcut operations on large timber. In West Virginia, ballooning would be impractical due to the high cost of both equipment and setup.

- Helicopters - Helicopter harvesting (see Figure IV-17) in Appalachia has been almost entirely confined to retrieving valuable timber on steep, inaccessible slopes or in areas where ground disturbance is forbidden. The primary reason for this is the high cost to own and operate a helicopter.

  However, companies specializing in helicopter harvesting services have been able to increase the productive use of their equipment through multicustomer scheduling and, consequently, are making helicopter harvesting more attractive economically as a normal harvesting technique. Helicopter harvesting can be accomplished over great distances without requiring an extensive logging road network.

Loading. Loading timber for transport from the harvesting area long has been one of the most costly and injury-plagued portions of a logging operation. Today, many of the manual techniques which were used have been replaced with safer and more productive mechanized techniques.

By far the most popular loading device in use today is the hydraulically controlled knuckle-boom loader. While many units are mounted directly on the transport vehicle, some are placed on separate vehicles to economize the use of one unit in



(Drawing Courtesy of U.S. Forest Service)

Fig IV-16 BALLOON CABLE YARDER

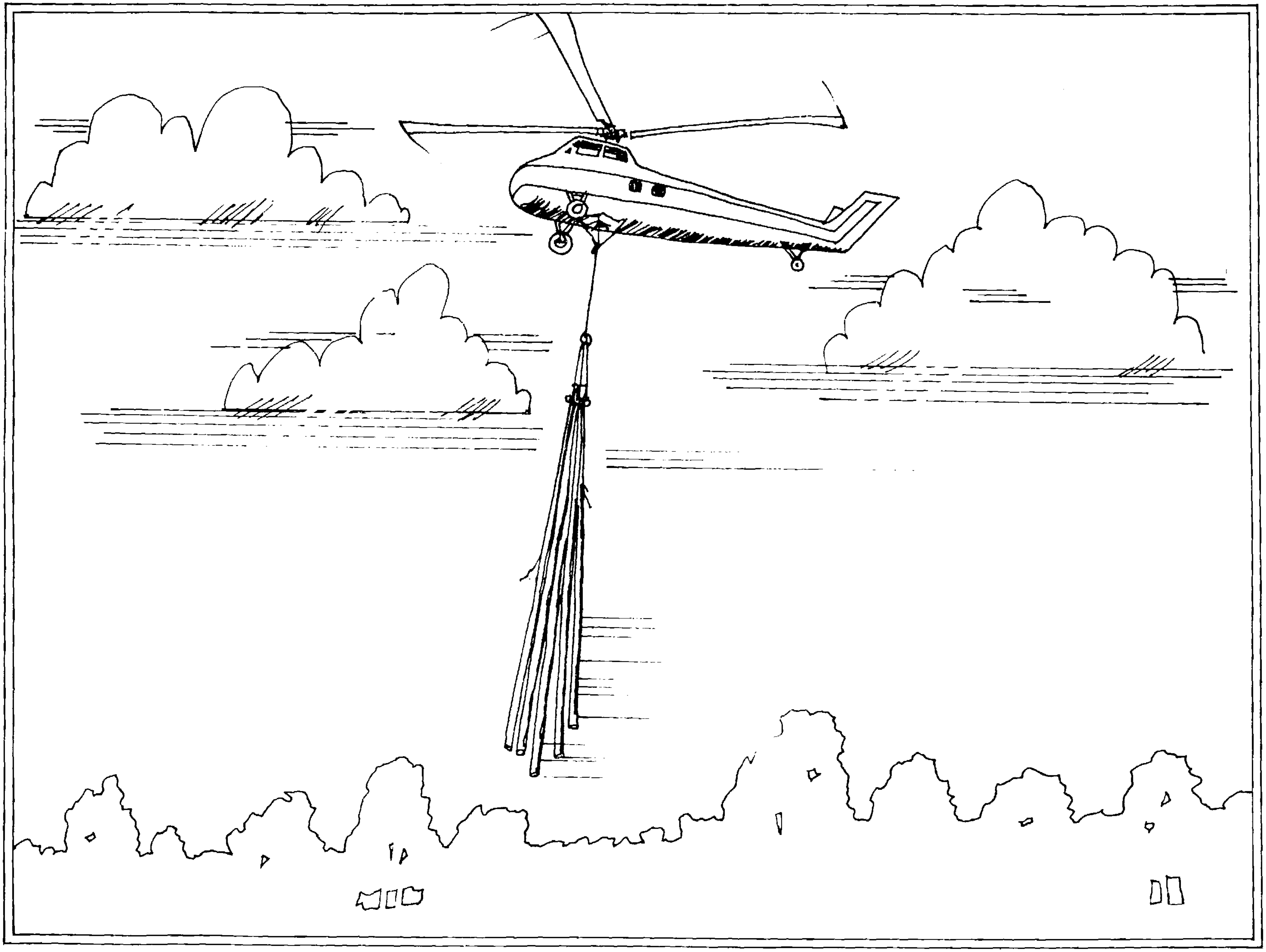


Figure IV-17. HELICOPTER

loading several transport vehicles.

Knuckle-boom loaders are highly productive units but lack the ability to reach out very far to pick up loads. Where material must be gathered over some distance for loading, either a cable or a front-end loader can be used.

Cable loaders are slow and drag the timber over the ground; however, they require little area in which to work. Front-end loaders employ hydraulic arms to speed productivity and elevate loads off of the ground. These units, however, require a considerable amount of work area in which to maneuver.

In addition to these conventional log loaders, there is a fourth system that is ideal for loading fuelwood. The system consists of a portable whole-tree chipper used in conjunction with a knuckle-boom loader. The loader feeds whole trees into the chipper, from which wood chips are blown into a waiting transport vehicle. The portable whole-tree chipper has reduced the need to transport trees or delimbed logs to a fixed chipper, thereby allowing greater utilization of all of the tree at the harvesting site.

- Knuckle-boom Loader - The knuckle-boom loader (see Figure IV-18) is a hydraulically controlled boom and grapple which can be mounted either on the transport vehicle or on a separate vehicle. The choice of mounting usually depends on the size of the loading operation, the landing layout, and the facilities at the other end of the transport haul.

  The knuckle-boom loader is versatile in the material it can handle. It can pick up short-length pulpwood or whole trees either as a single piece or several pieces. One man is all that is needed to perform the loading operation; consequently, this process is more economical and much safer than those requiring more use of manual labor. Typical units can cost from $30,000 to $80,000.

- Cable Loaders - The cable loader (see Figure IV-19) can drag pieces of timber from considerable

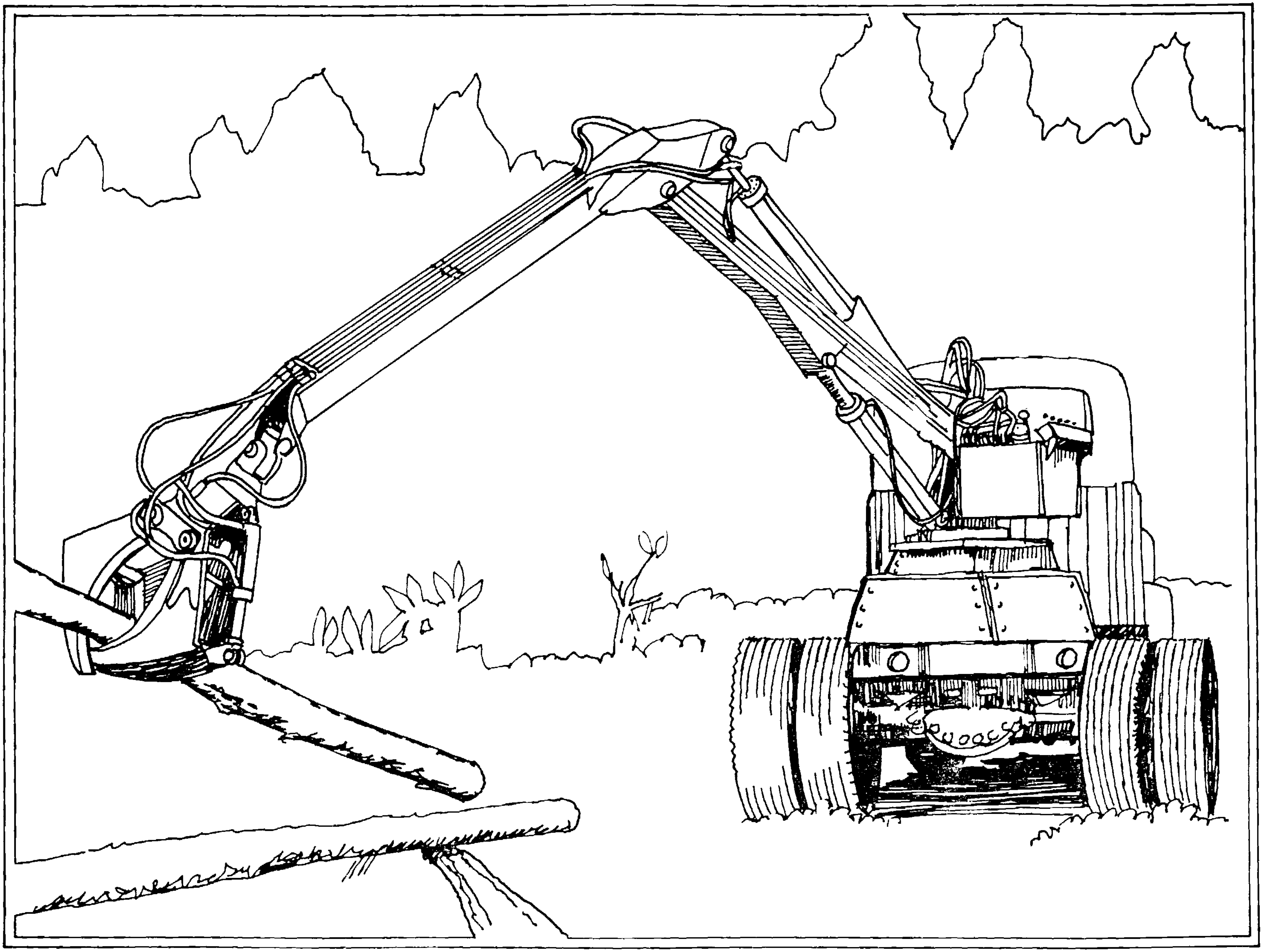


Figure IV-18. KNUCKLE-BOOM LOADER

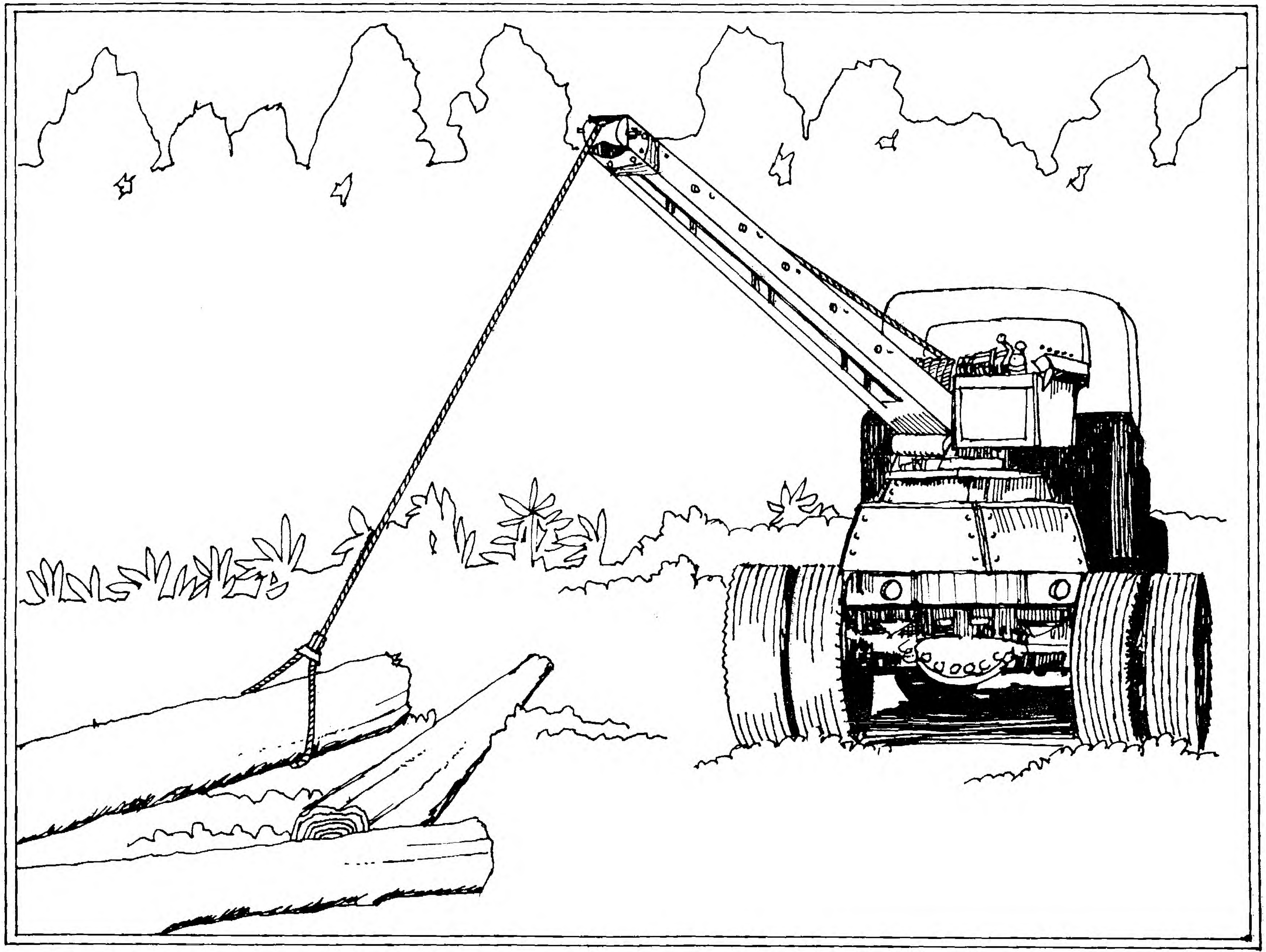


Figure IV-19. CABLE LOADER

distances, often as much as 150 feet. The process does require a hookup man on the ground and a top unloading man on the transport vehicle to hook and unhook the cable, respectively.

Cable loaders are actually small cranes and, like knuckle-boom loaders, can be mounted either on the transport vehicle or on a separate vehicle. Due to the time involved in setting and unhooking cables, as well as the dangers of handling cable, these loading operations are slower than knuckle-boom loading and more risky as far as the threat of injury. Units can cost from $15,000 to $40,000.

- Front-end Loaders - A front-end loader is a wheeled or tracked vehicle equipped with a pair of lifting arms or grapples on its front end (see Figure IV-20). Due to its requirement to move about in the loading operation, front-end loaders require considerable amounts of firm ground on which to maneuver and hence are more frequently used in stock yards rather than harvesting landings. They can cost anywhere from $50,000 to $80,000.

- Whole-tree Chippers - A variety of mobile wood chippers are now available for use at the harvesting landing (see Figure IV-21). Some models debark and degrit the chips to allow their use as pulp stock. These devices tend, however, to be unwieldly and expensive. Newer designs can be found which are smaller and lack separation capability, but are much less expensive. Such units appear ideal for generating fuelwood-grade chips. Chippers can cost from $50,000 for a small unit to $180,000 for a large unit.

Road Building and Maintenance. Perhaps one of the most fundamental aspects of timber harvesting is the building and maintaining of logging roads. There are three basic types of logging roads in existence: 1) truck road, 2) forwarder road, and 3) skid road. Each road type must be designed to the grade and surface requirements of its intended use. Primary roads usually supply access to several logging operations and are built to be somewhat permanent. Secondary roads, on the other hand, are usually intended for use on a single operation and are usually abandoned when that operation is finished.

Figure IV-20. FRONT END LOADER

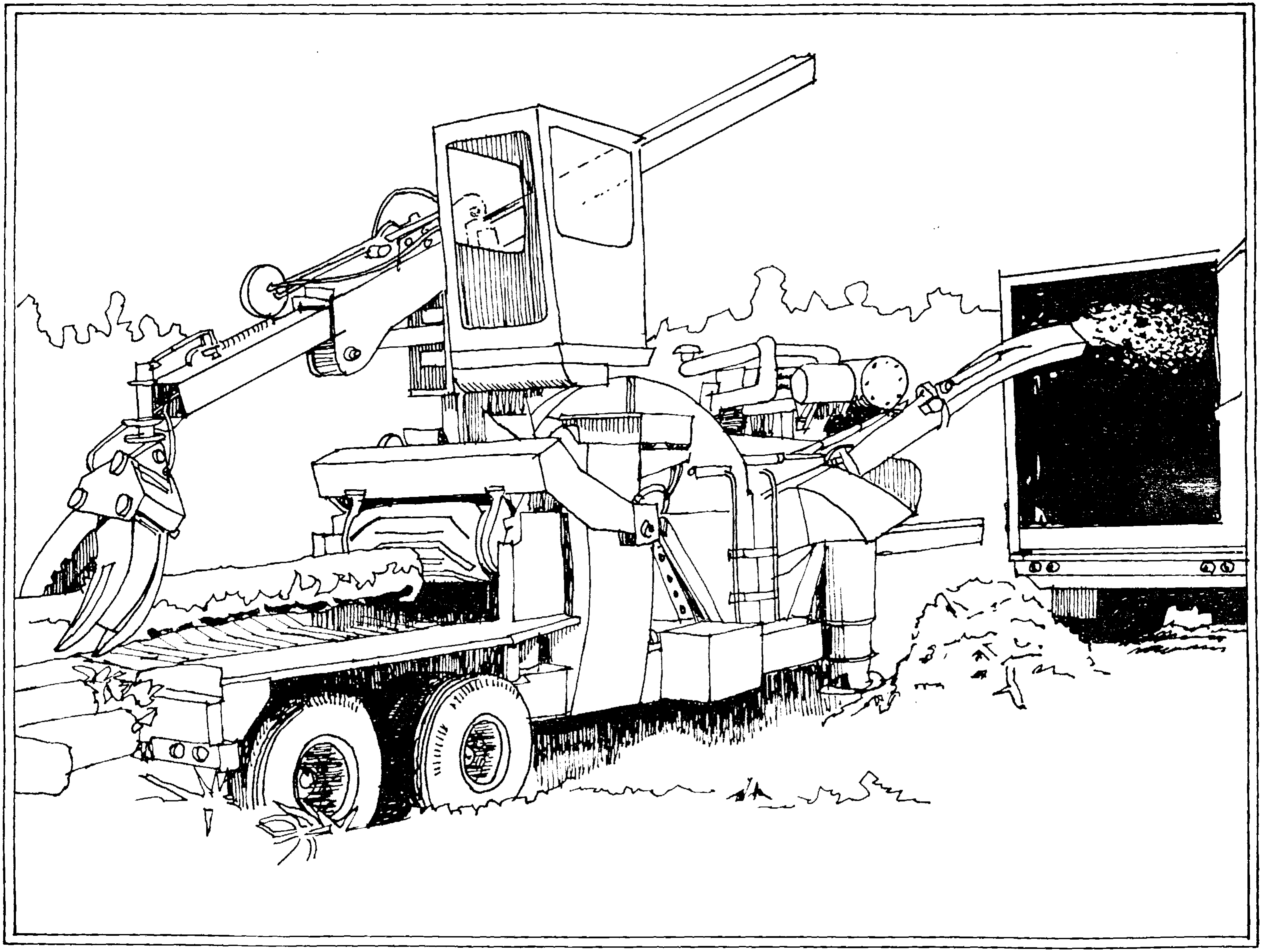


Figure 21. WHOLE TREE CHIPPER

Most roads require the use of a crawler tractor equipped with a bulldozer blade to carve the road bed. Loaders may be needed to transport fill dirt and gravel, but usually on more permanent primary roads only.

Once constructed, a road requires periodic grading to fill in ruts. This is usually done by a grader on more permanent primary roads and by a bulldozer on less permanent roads. In the case of skidding operations on steep slopes, the dozer used to perform the skidding usually maintains the skid-road system to the landing as well.

Harvesting Equipment Costs

Depending on the level of effort to be mounted by a company engaged in the harvest of fuelwood, the necessary investment can quickly become quite large when the purchase prices of all the machines are totalled. Purchase prices for certain types of harvesting machinery were collected by the Georgia Forestry Comission in 1978 and are presented in Table IV-1. Operating costs are also estimated.

Transporting Fuelwood

There are three basic means of transporting wood chips from the harvesting site to an industrial user: barge, rail, and truck. Figure IV-22 displays the principal waterways in West Virginia that are suitable for barge traffic. Similarly, Figures IV-23 and IV-24 show major rail lines and highways, respectively, in the state.

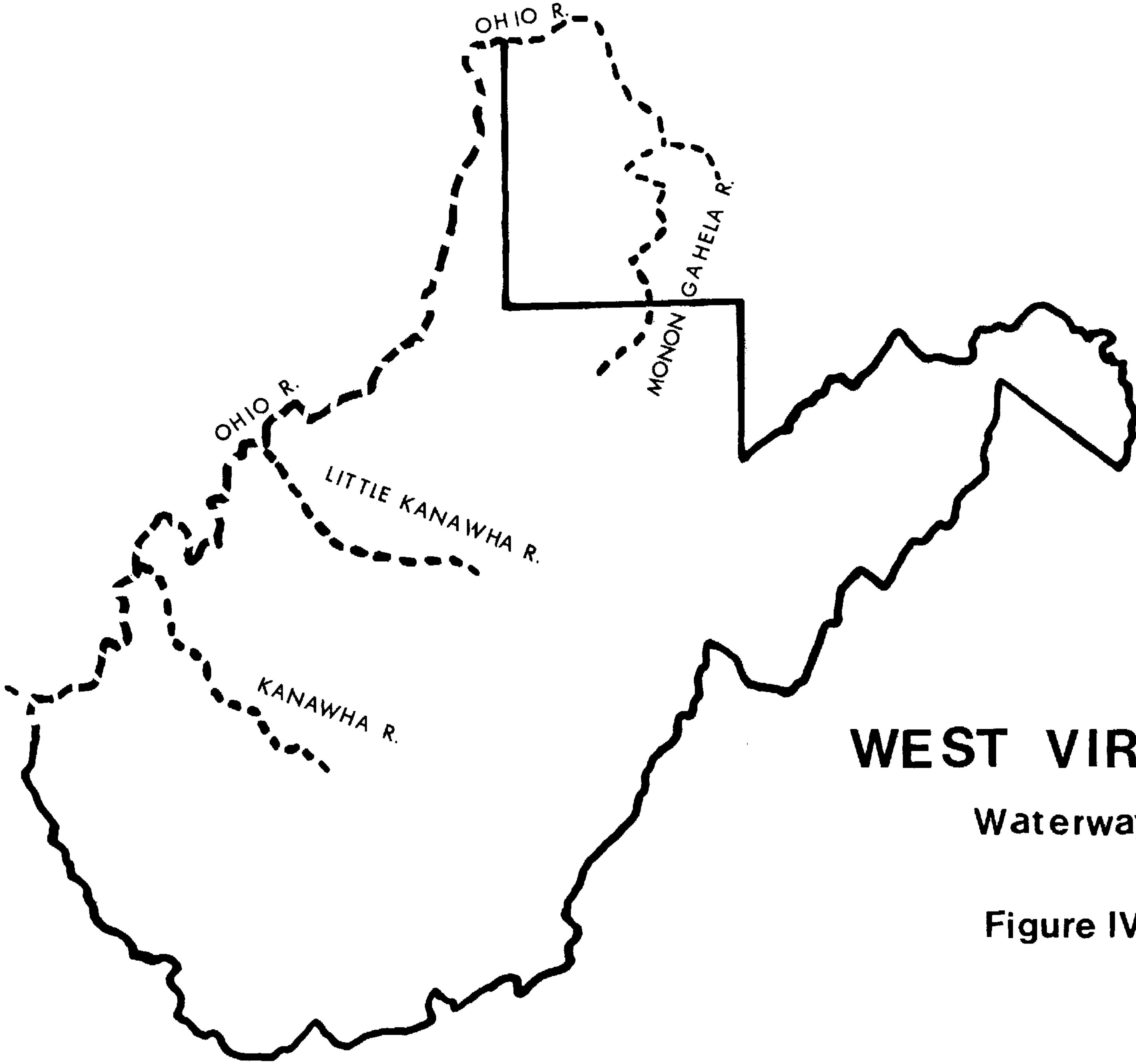
Commercial transportation rates are most appropriately compared in terms of cost per ton-mile. Barge rates are easily the least costly of the three transportation modes, averaging 0.3 cents per ton-mile, but barging is severely restricted in its usefulness by geography. While it could

Table IV-1

SOME SELECTED 1978 HARVESTING MACHINE COSTS AND RATES

Equipment	Purchase Cost	Years Life	Cost/Mile-Hour Fixed	Cost/Mile-Hour Operating	Total
Cable Skidder	$ 42,000	4	$ 12.86	$ 7.78	$ 20.64 hr.
Grapple Skidder	56,000	4	14.66	6.12	20.78 hr.
Bobcat Feller Buncher	42,000	4	9.12	9.06	18.18 hr.
Hydo-Axe 311 Feller Buncher	56,000	4	8.08	5.88	13.96 hr.
Hydo-Axe 511 Feller Buncher	73,000	4	12.20	7.10	19.30 hr.
Franklin 170 Feller Buncher	58,000	4	7.90	6.42	14.32 hr.
Mobile Chipper 22"	178,000	5	22.06	12.30	34.36 hr.
Mobile Chipper 12"	48,000	5	6.66	8.42	15.08 hr.
Chain Saw, Large (straight blade)	450	1	--	2.35	2.35 hr.
Single Axle Gas Truck Tractor	13,500	4	0.16	0.52	0.68 mi.
Tandem Gas Truck Tractor	21,500	4	0.18	0.47	0.65 mi.
Single Axle Diesel Truck Tractor	30,000	6	0.12	0.30	0.42 mi.
Tandem Diesel Truck Tractor	42,000	6	0.14	0.38	0.52 mi.
Chip Van	11,500	10	0.06	0.05	0.11 mi.

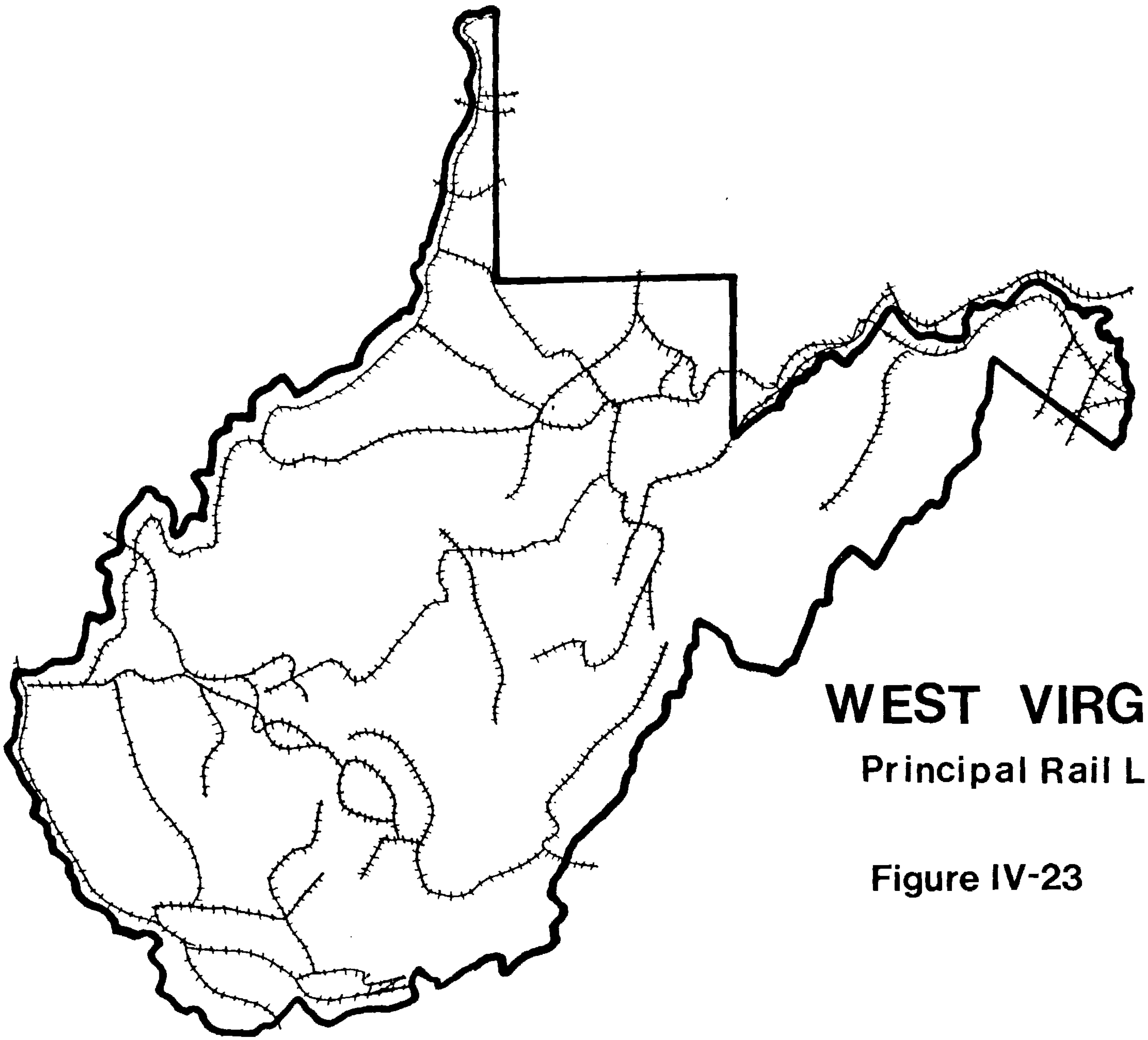
Source: Georgia Forestry Commission



WEST VIRGINIA

Waterways

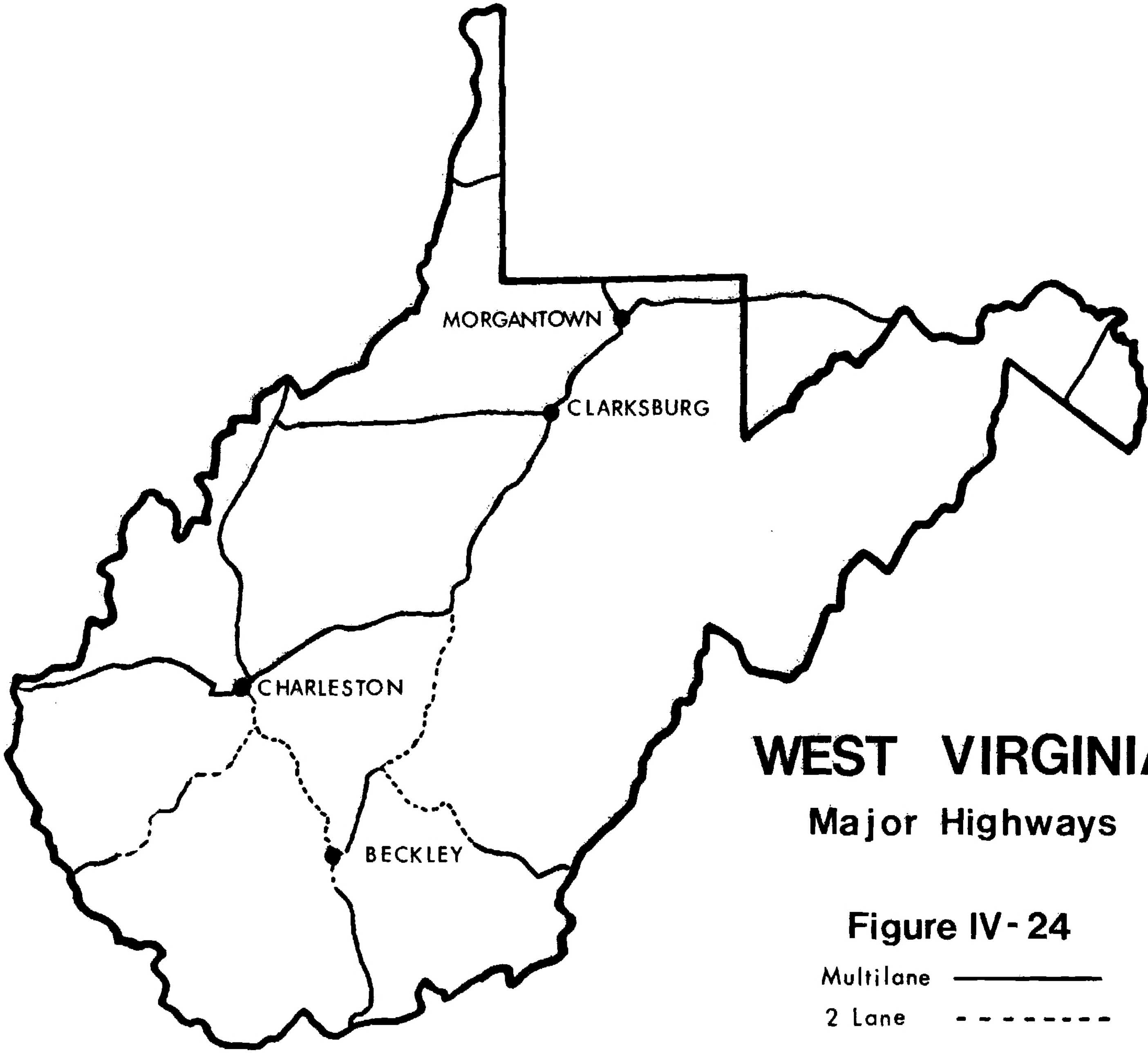
Figure IV-22



WEST VIRGINIA

Principal Rail Lines

Figure IV-23



WEST VIRGINIA

Major Highways

Figure IV-24

Multilane ————

2 Lane - - - - - - - -

prove feasible to barge if both the chip harvesting site and the industrial user were near a waterway, any other scenario would require incurring substantial costs for connecting transportation and cargo transfer. Barging, therefore, should be relegated to consideration only under specialized circumstances.

Tables IV-2 and IV-3 present, respectively, rail and truck rates for hauling wood chips by common carrier in West Virginia. In both cases the rates clearly decrease for longer haul distances; truck rates also are affected by the type of road or highway traversed, with interstate highways having the lowest rates and unpaved roads the highest. An interesting point to note is that the rail rates for wood chips, as with other commodities, vary depending on the end use of the commodity. The rates shown in Table IV-2 are for wood chips that will be used as fuel. In contrast, chips that are to be utilized in pulp and paper production are charged rail rates that range from only one-third to one-half as much. This practice discourages the use of rail for moving fuelwood chips.

Beyond the common carrier rates charged for transportation, the other major cost in this category relates to loading and unloading the cargo. The two most common types of rail-car unloading systems are bottom-dump rail cars with receiving hoppers under the track shown in Figure IV-25, and rotary car dumpers that actually invert the rail cars individually as illustrated in Figure IV-26. Trucks are nearly always unloaded by a hydraulic dumping mechanism; the truck is driven onto a platform which is then pivoted as shown in Figure IV-27. Self-unloading vans that employ a drag chain arrangement to eject the chips are occasionally used. As noted in Table IV-3, the hauling rates will be higher when these self-unloading vans are specified by a motor freight customer.

The various unloading systems can be quite costly. For example, a typical hydraulic truck-dumping arrangement would

Table IV-2

RAIL RATES for WOOD CHIPS

(60,000 lbs minimum weight)

RAIL DISTANCE (miles)	RATES (¢/100 lb.)	(¢/ton-mile)
50	42	17
100	56	11
150	64	9
200	72	7
250	77	6
300	86	6
350	94	5

Table IV-3

TRUCK RATES for WOOD CHIPS

DISTANCE (miles)	RATES (¢/ton-mile) Interstate	Secondary road	Off highway
up to 10	15	16	18
10 to 20	13	14	16
20 to 50	11	12	14
greater than 50	9	10	12

NOTE: Add 1¢/ton-mile when specifying self-unloading van

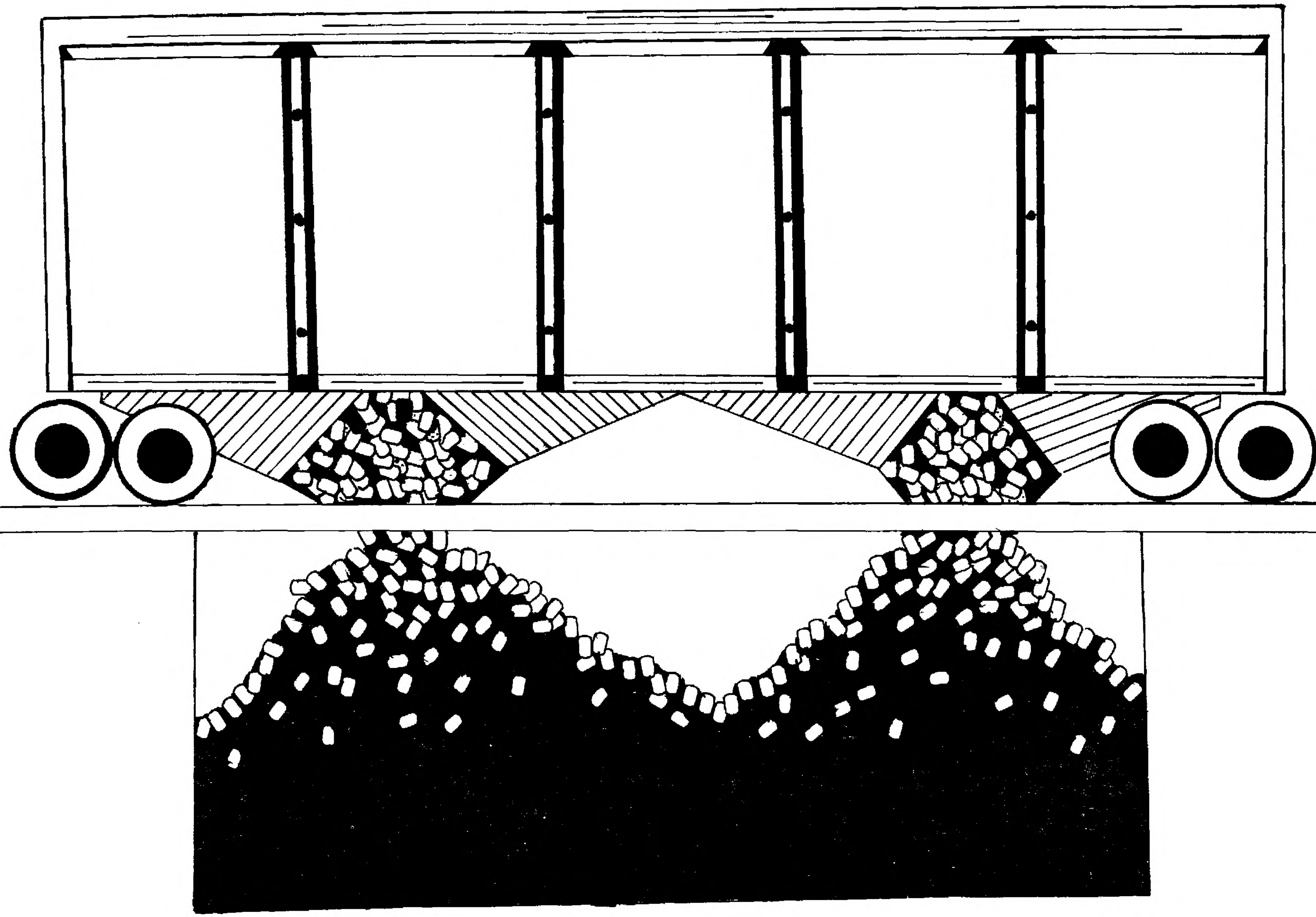


Fig IV-25 **BOTTOM DUMP UNLOADING**

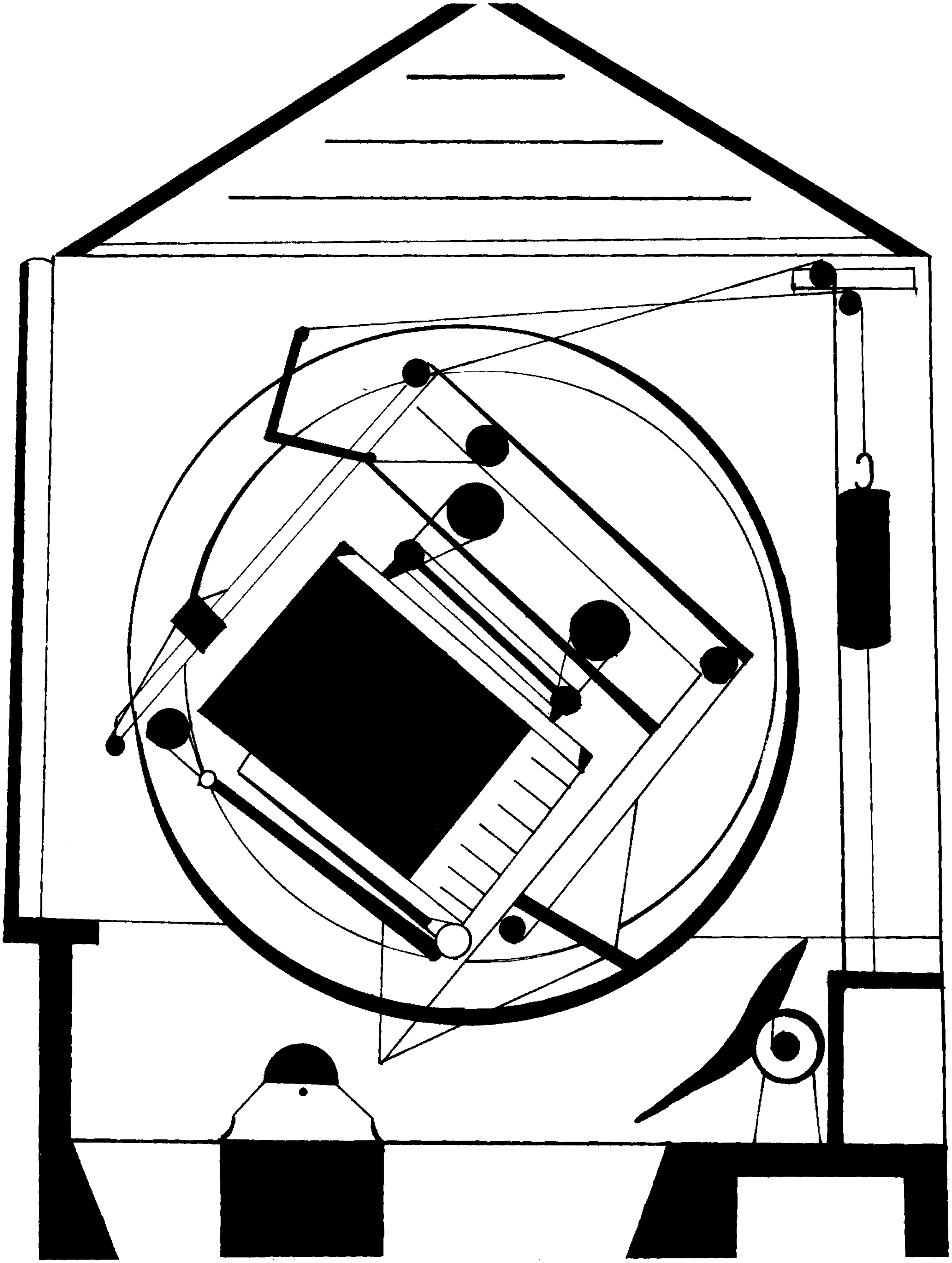


Fig IV-26 **ROTARY DUMP UNLOADING**

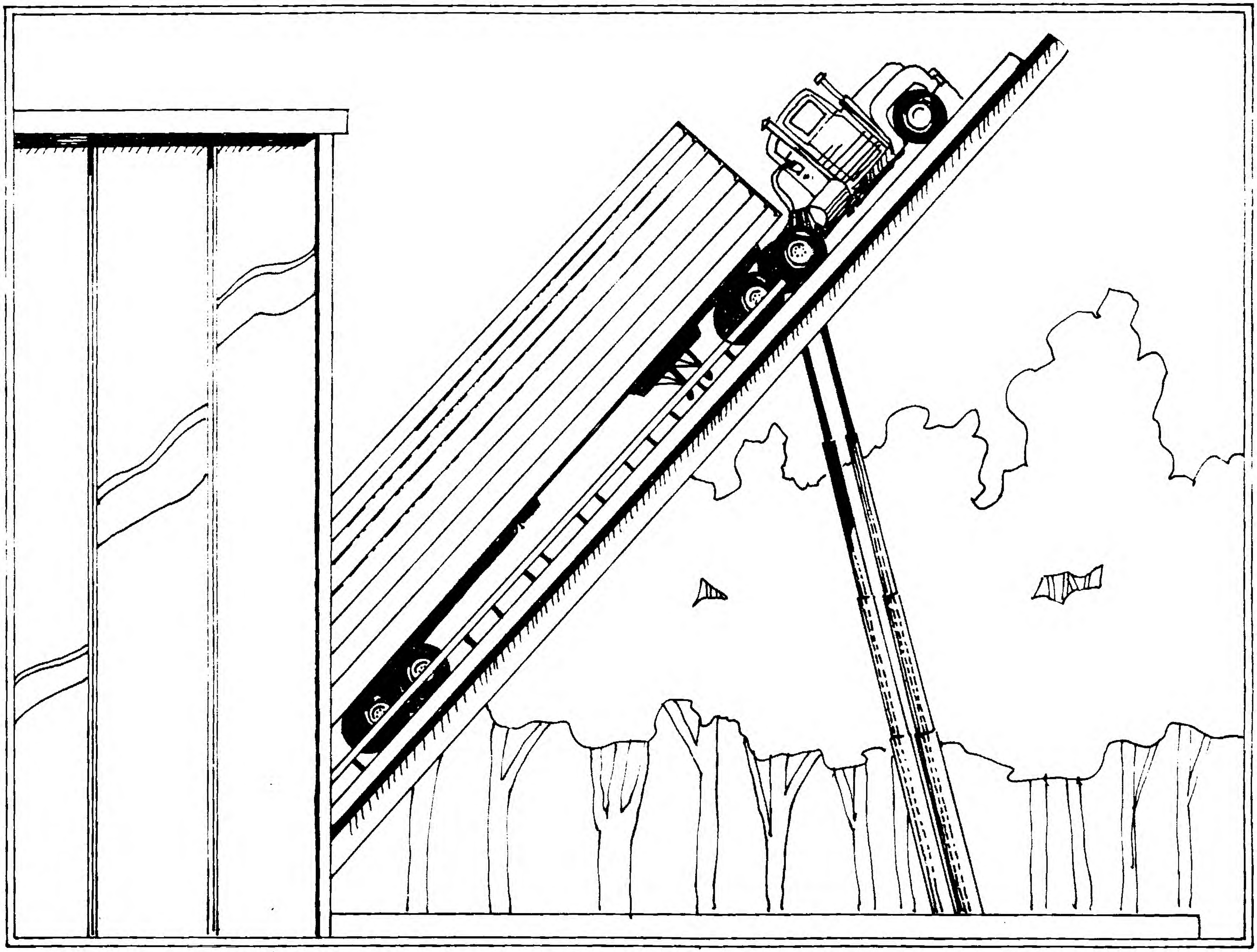


Fig IV-27 **HYDRAULIC TRUCK DUMP**

run about $250,000, while an average rail under-track hopper and conveyor system would cost in the vicinity of $125,000. Rotary rail car dumping equipment is easily the most expensive, with a basic unit costing in excess of $350,000.

The total transportation cost, then, would depend not only on the common carrier rates, but also on the number of cargo transfers required. Figure IV-28 presents total rail and truck transportation costs over a range of hauling distances. The truck rate curve essentially reflects Table IV-3, whereas the rail curve assumes an initial truck haul of 30 miles to bring the chips from the harvest area to a rail siding for loading. The transfer costs from the van to the rail car are also included at the rate of $0.75 per ton. The graph shows, as a result, that with a haul of less than about 175 miles, truck is more economical than rail. The situation reverses with longer distances.

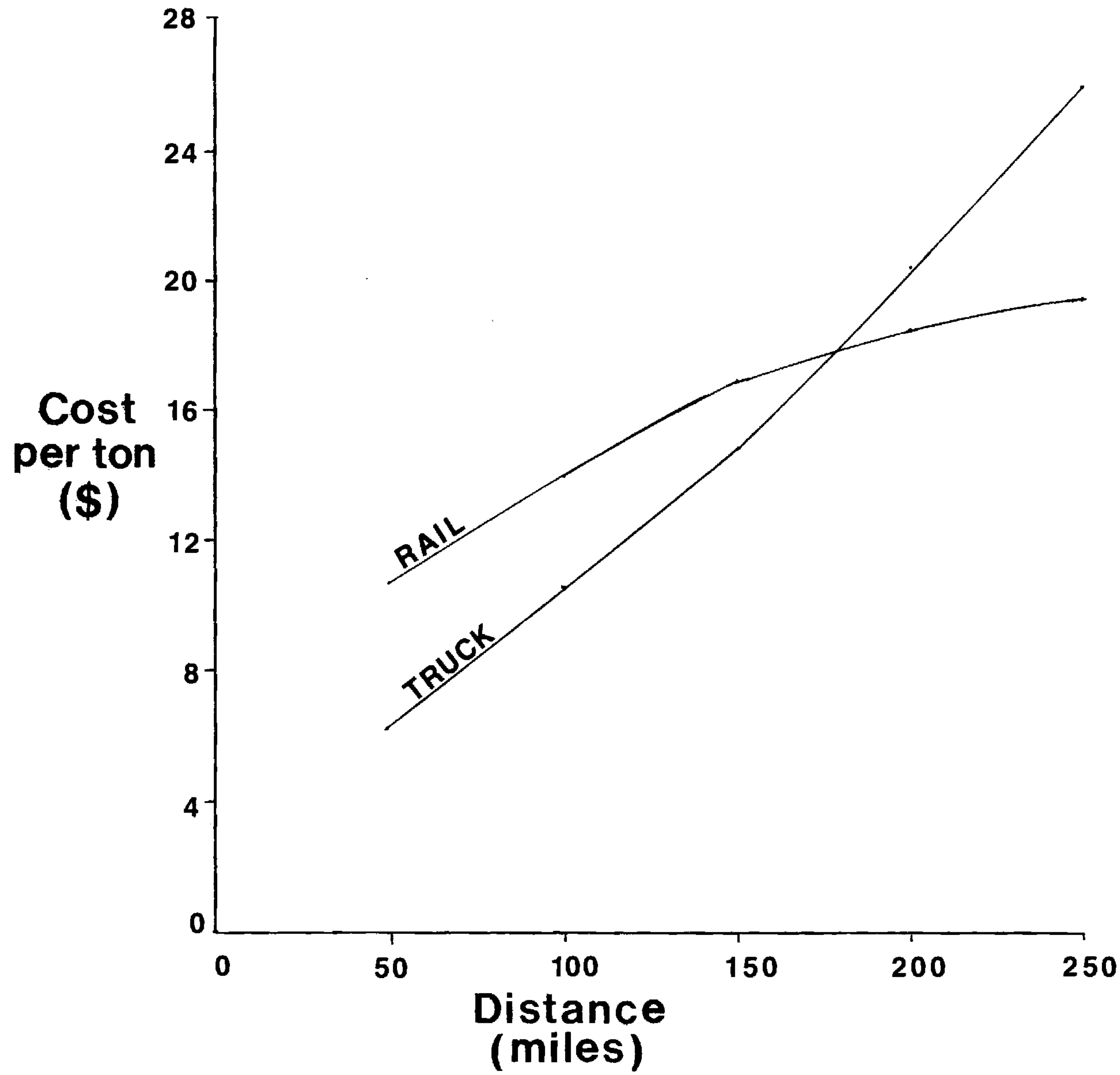
Economics of Whole-Tree Chipping

In West Virginia, approximately 20% of the state has topography suitable for a totally mechanized felling, retrieval, and chipping operation. The remaining 80% of the state requires a manual element in both the felling and retrieval processes brought about by the steep, hilly terrain. This evaluation of whole-tree chipping for West Virginia considers this proportion of steep and flat terrain harvesting, as well as the possible variation in technique for scaling the hillsides. For this analysis, three systems are considered.

The operations of all three systems on flat terrain can be handled by more conventional mechanized felling equipment to increase harvesting productivity. Mechanical feller-bunchers can be used to shear off trees at the base and accumulate several trees into piles for retrieval from the forest. From there wheeled skidders can be used to retrieve felled timber

Figure IV-28

TRANSPORTATION COSTS



to a central loading site. Due to the few restrictions placed on equipment maneuverability on flat land, hydraulic grapple arms can provide a quicker and safer alternative to logging chains and cables. Once brought to the landing, a whole-tree chipper can then be used to convert the tree into chips for transport.

Where the systems vary will be on hillside operations. The most common system used in West Virginia is the skidding system shown in Figure IV-29. This system is composed of a bulldozer for retrieval, a chain saw for felling, and a mobile whole-tree chipper for wood energy purposes. The use of tracked equipment is essential in providing the earthmoving power to build skid roads on the hillside and keep them in good repair. Due to maneuverability restrictions which require equipment to stay on the skid road, logging chains and cables are commonly used to pull felled trees to the skidder for retrieval.

The second harvesting system which has great potential for use in West Virginia is the cable harvesting system. A typical cable harvesting setup is shown in Figure IV-30. This system is composed of the cable yarder and a tailspar, which can be either a tree or a piece of equipment such as the bulldozer shown, a chain saw for felling, a wheeled skidder to move trees from the cable yarder to a landing where, for wood energy purposes, a mobile whole-tree chipper is located.

The third harvesting system used in West Virginia is currently limited to retrieving valuable tree stands which cannot be harvested by any other technique. This method is the helicopter harvesting system and is shown in Figure IV-31. It is composed of a helicopter for retrieval, chain saw for felling, and a wheeled skidder to move trees from the drop point to a landing where, for wood energy purposes, a whole-tree chipper is located.

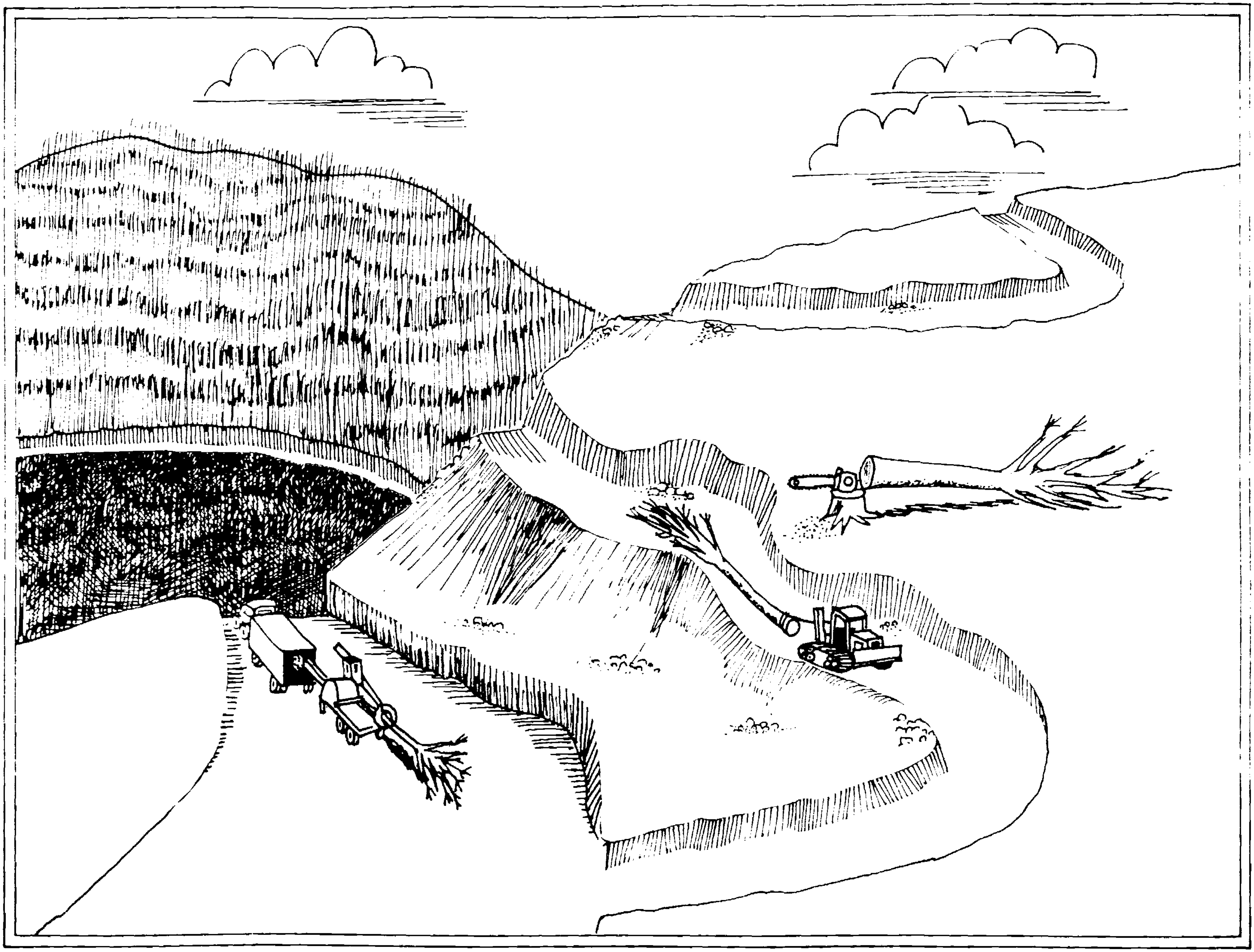


Fig IV- 29 **SKIDDER HARVESTING**

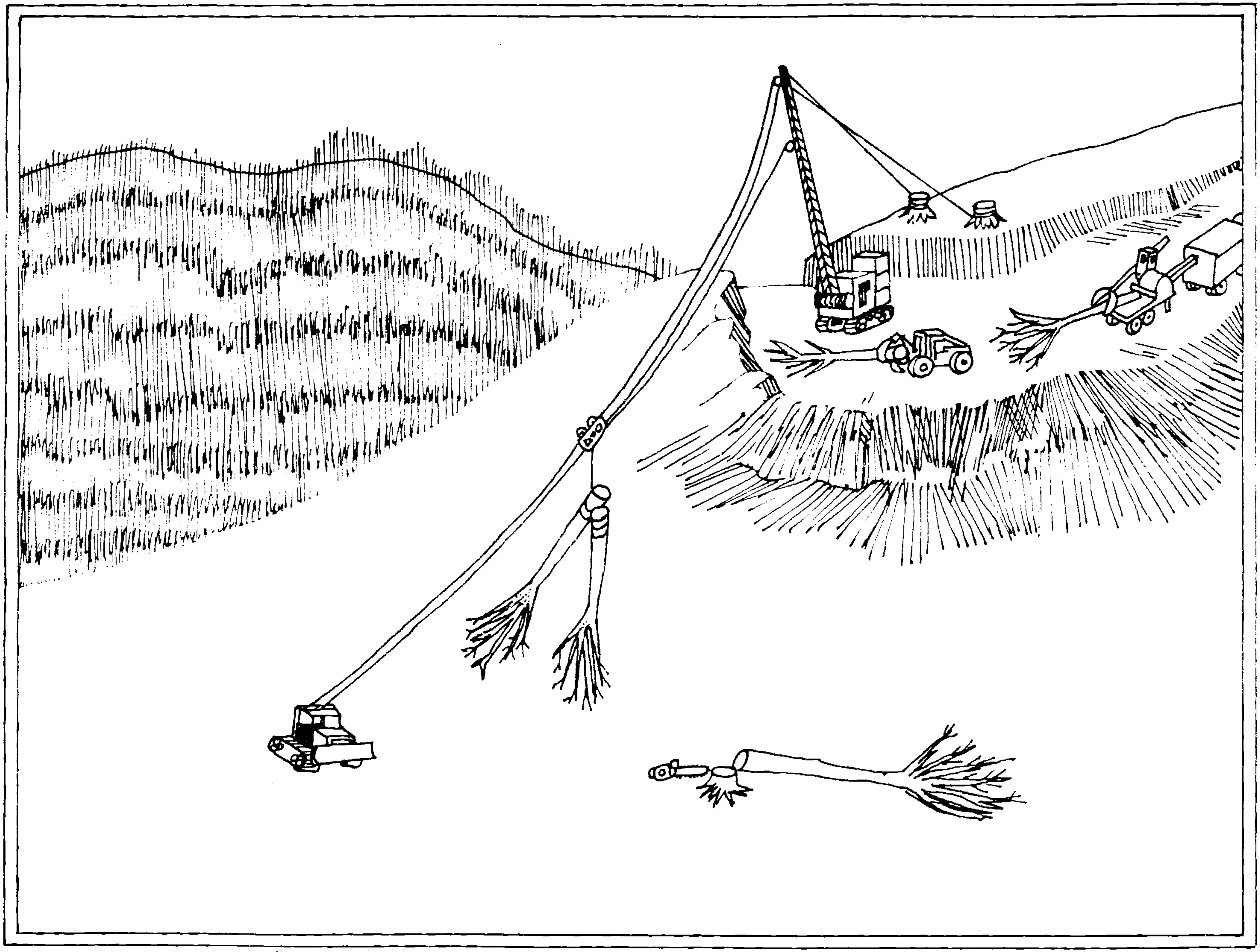


Fig IV-30 **CABLE YARDER HARVESTING**

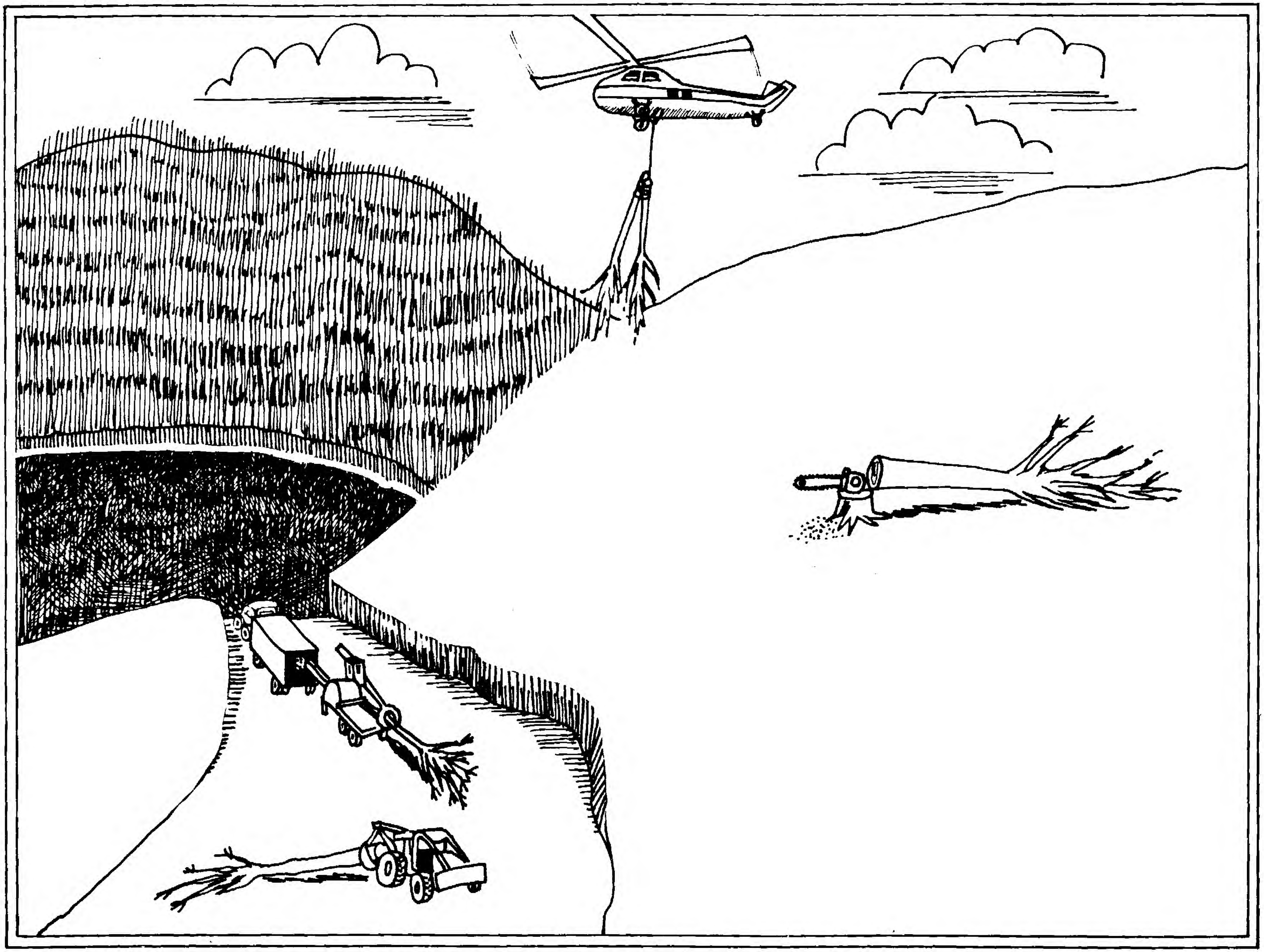


Fig IV-31 **HELICOPTER HARVESTING**

In order to estimate typical costs, it is first necessary to establish typical operating criteria. This analysis will be limited to whole-tree chipping. Further, a 50-week-per-year operation will be assumed, working 40 hours per week, with productivity limited by practical consideration of equipment and logistics.

There are several variables which have major effects on the costs of harvesting and transporting wood chips. Since the analysis is limited to chipping, one variable is eliminated. Another variable is the type of harvesting: clear-cutting, selective thinning, timber stand improvement, etc. These will affect the productivity rates of the operation because of the distances traveled to deliver trees to a landing; when these distances become too great, the landing must be moved to another central location. Both of these difficulties reduce productivity. A third variable is the size of the operation, in terms of both machinery and labor. The size of the chipper will serve as the guide to how many feller-bunchers, skidders, and tractor/chip vans are required. Operations of optimal size should keep the chipper in operation approximately 65% of the time. The final variable, of course, is the timber stand itself. The density and average diameters of the trees determine the volume of wood which can be collected and chipped in a given period.

Because of the range and importance of the variables discussed above, the productivity and unit costs of harvesting are very site-specific. This analysis, therefore, attempts only to present a "representative" case, which is a combination of data received from private loggers in West Virginia, U.S. Forest Service studies, and published reports.

Based on these assumptions and utilizing the best available data, calculations were made of the estimated unit costs of a harvesting, chipping, and transporting operation utilizing clearcut, in-field, whole-tree chipping of timber with an 8-inch average diameter at breast height. Table IV-4 shows that the estimated average cost per ton (green) to harvest and transport fuelwood using the skidding harvesting system is $22.96. Assuming an average heating value for green wood of 8.6 million Btu's per ton, the average cost of this system per million Btu's is $2.67. Table IV-5 shows that the estimated average cost per ton (green) to harvest and transport fuelwood using the cable harvesting system is $26.73, or $3.11 per million Btu's. Comparable estimated cost per ton using the helicopter harvesting system is $44.83, or $5.21 per million Btu's as detailed in Table IV-6.

Table IV-4

ESTIMATED UNIT COST TO HARVEST AND TRANSPORT FUELWOOD
USING SKIDDING HARVESTING SYSTEM

Hillside Operation

	Productivity/Machine	Cost/Machine Fixed	Cost/Machine Operating
3 Skidders	6 tons/hr.	$12.86/hr.	$ 7.78/hr.
3 Chain saws	7 tons/hr.	--	2.35/hr.
1 Chipper	20 tons/hr.	11.74/hr.	10.42/hr.
	system productivity	system cost	
	18 tons/hr.	$50.32/hr.	$40.81/hr.
		$91.13/hr.	

	Cost/Ton (Green)
Equipment	$ 5.06
Labor (10 men @ $6.50/hr.)	3.61
Support Equipment (pickup truck, backup saws, etc.)	.40
Insurance Benefits, Workers Comp.	1.81
Overhead	2.02
Transportation (50 miles by truck 20 miles secondary road 30 miles interstate highway)	5.70
Skid Road Construction	2.10
Profit and Taxes (20% of Equipment, Transportation, Labor)	2.95
SUBTOTAL	$23.65
Stumpage	1.20
	$24.85

Flatland Operation

	Productivity/Machine	Cost/Machine Fixed	Cost/Machine Operating
1 Skidder	20 tons/hr.	$14.66/hr.	$ 6.12/hr.
1 Feller/Buncher	21 tons/hr.	9.12/hr.	9.06/hr.
1 Chipper	20 tons/hr.	11.74/hr.	10.42/hr.
	system productivity	system cost	
	20 tons/hr.	$35.52/hr.	$25.60/hr.
		$61.12/hr.	

Table IV-4 (Continued)

Flatland Operation (Continued)

	Cost/Ton
Equipment	$ 3.06
Labor (5 men @ $6.50/hr.)	1.62
Support Equipment (pickup truck, backup saws, etc.)	.36
Insurance Benefits, Workers Comp.	.71
Overhead	.91
T ansportation	5.70
(50 miles by truck	
20 miles secondary road	
30 miles interstate highway)	
Profit and Taxes (20% of Equipment, Transportation, Labor)	1.85
SUBTOTAL	$14.21
Stumpage	1.20
	$15.41

Average cost of Skidding System

80% Hilly - $24.85 x .8
20% Flat - 15.41 x .2

$22.96/ton or $2.67/mmBtu*

*Assuming an average heating value for green wood with 50% moisture content of 8.6 million Btu/Ton.

Table IV-5

ESTIMATED UNIT COST TO HARVEST AND TRANSPORT FUELWOOD
USING CABLE HARVESTING SYSTEM

Hillside Operation

	Productivity/Machine	Cost/Machine Fixed	Cost/Machine Operating
1 Cable Yarder	9.5 tons/hr.	$18.57/hr.	$ 9.12/hr.
1 Skidder	17 tons/hr.	12.86/hr.	7.78/hr.
2 Chain saws	7 tons/hr.	--	2.35/hr.
1 Chipper	20 tons/hr.	11.74/hr.	10.42/hr.
	system productivity	system cost	
	9.5 tons/hr.	$43.17/hr.	$32.02/hr.
		$75.19/hr.	

	Cost/Ton (Green)
Equipment	$ 7.91
Labor (5 men @ $6.50/hr.	4.79
Support Equipment (pickup truck, backup saws, etc.	.76
Insurance Benefits, Workers Comp.	2.69
Overhead	2.68
Transportation (50 miles by truck 20 miles secondary road 30 miles interstate highway)	5.70
Profit and Taxes (20% of Equipment, Transportation, Labor)	3.83
SUBTOTAL	$28.36
Stumpage	1.20
	$29.56

Flatland Operation (See System I)

Cost/Ton

$15.41

Average Cost of Cable System

80% Hilly - $29.56 x .8
20% Flat - 15.41 x .2

$26.73/ton or $3.11/mmBtu

Table IV-6

ESTIMATED UNIT COST TO HARVEST AND TRANSPORT FUELWOOD
USING HELICOPTER HARVESTING SYSTEM

Hillside Operation

	Productivity/Machine	Cost/Machine Fixed	Cost/Machine Operating
1 Helicopter	70 tons/hr.	$ --	$1,800/hr.
10 Chain saws	7 tons/hr.	--	2.35/hr.
3 Skidders	25 tons/hr.	14.66/hr.	6.12/hr.
2 Chippers	35 tons/hr.	22.06/hr	12.30/hr.
	system productivity	system cost	
	70 tons/hr.	$88.10/hr.	$1,866.46/hr.
		$1,954.56/hr.	

	Cost/Ton (Green)
Equipment	$27.92
Labor (18 men @ $6.50/hr + 4 men @ $11.00/hr.)	2.30
Support Equipment (Pickup, backup saws, etc.)	.40
Insurance Benefits, Workers Comp.	6.12
Overhead	1.29
Transportation (50 miles by truck: 20 miles secondary road, 30 miles interstate highway)	5.70
Profit and Taxes (20% of Equipment, Transportation, Labor)	7.26
SUBTOTAL	$50.99
Stumpage	1.20
	$52.19

Flatland Operation (See System 1)

	Cost/Ton
	$15.41

Average Cost of Helicopter System

80% Hilly - $52.19 x .8 $44.83/ton or $5.21/mmBtu
20% Flat - 15.41 x .2

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V. CONVERSION OF WOOD TO ENERGY

Wood Fuel Preparation

Wood can be utilized as a fuel in a number of different forms. The two general classifications considered here are wood chips (and residue) and densified wood. The former category includes chips from total tree chippers, "hog" fuel, and various types of residues from manufacturing operations, such as bark, planer shavings, sawdust, sander dust, and "ends and slabs" (larger pieces left over from dimensioned lumber finishing). Densified wood is the product of a process that makes the wood feedstock moldable; the result is a uniformly sized particle having a density about twice that of natural wood (comparison based on samples with the same moisture content). Densification is discussed in more detail in a later section.

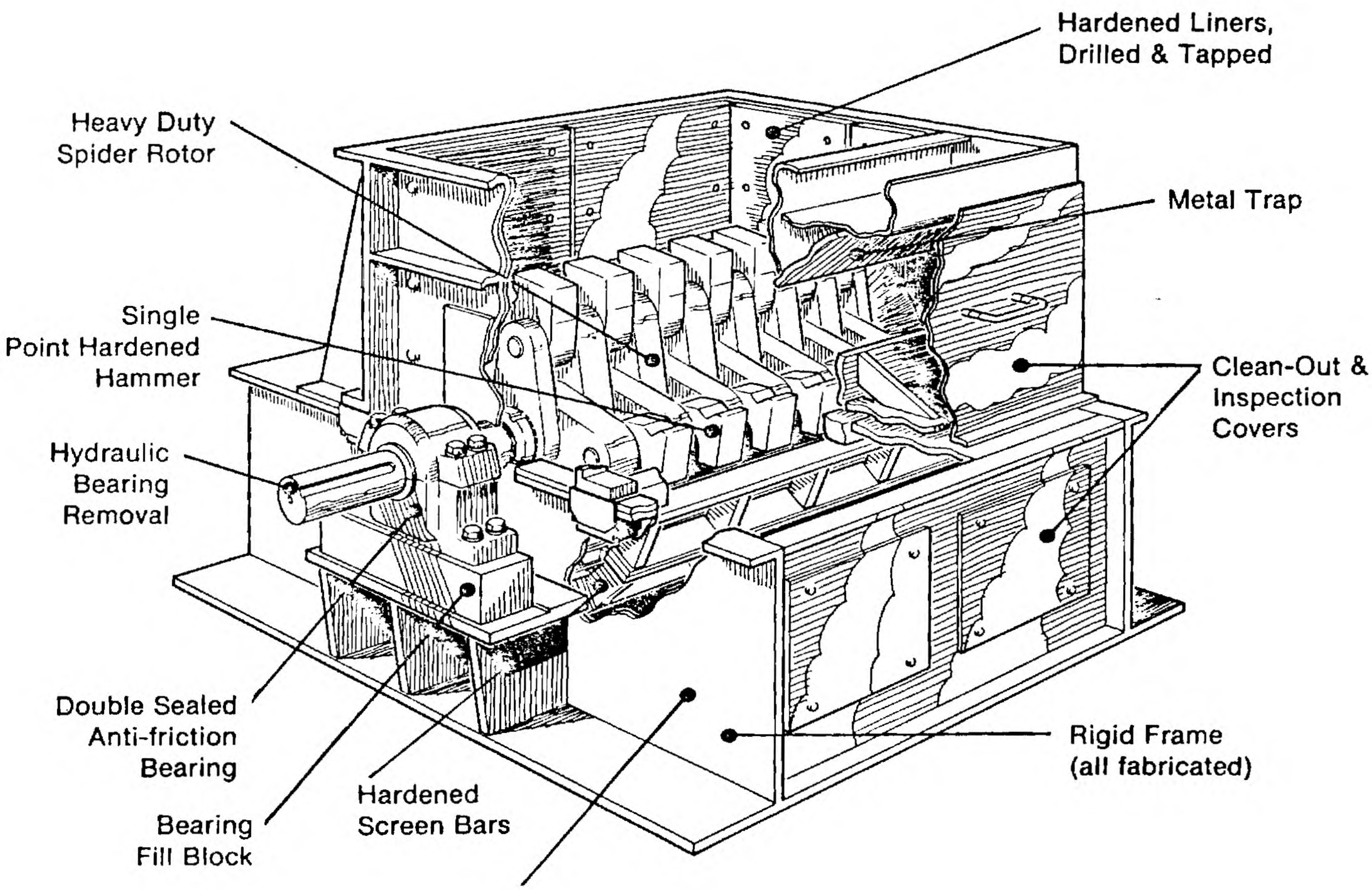
"Total" or "whole tree chips" are produced by mobile pieces of equipment ("chippers") that are capable of pulling an entire tree (up to 20 inches in diameter for the largest models) into the chipping blades and reducing it to small pieces which are blown into a waiting truck. "Hog" fuel refers to wood that has been broken into small pieces by a hammermill or "hog."

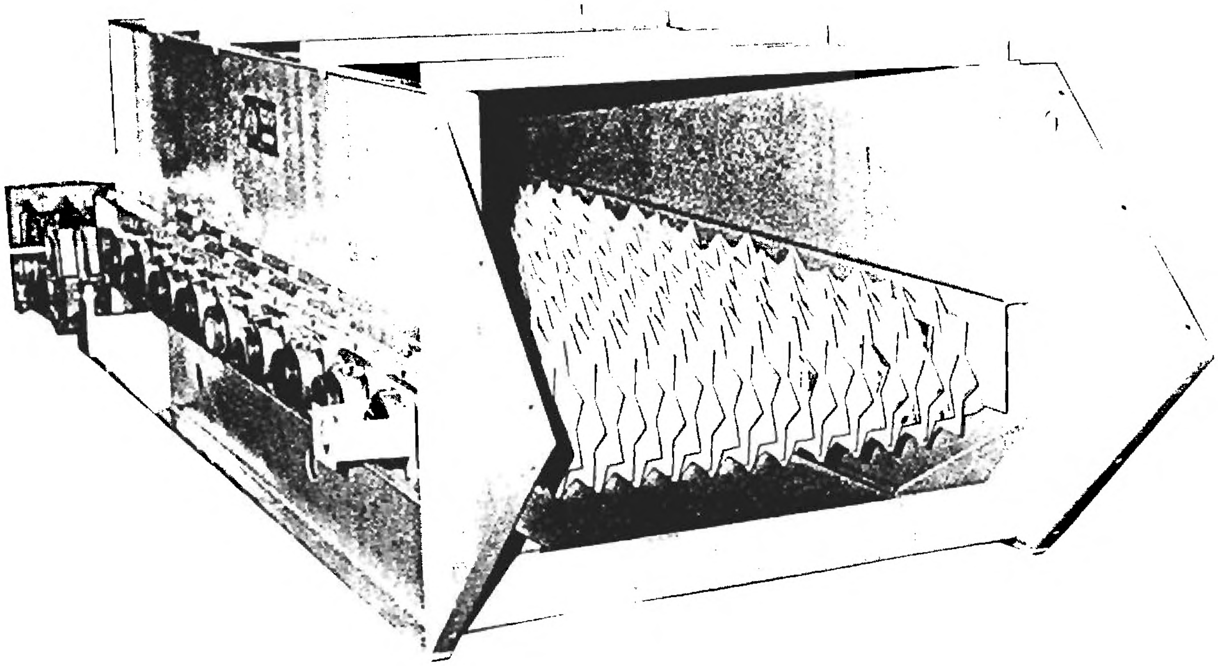
Preparing wood for use as a fuel requires that a number of steps be taken. These steps are primarily involved with sizing and/or drying the fuel particles. Sizing is generally accomplished by the hammermill or "hog" mentioned earlier, which is frequently preceded by a preliminary sizing stage, such as screening, to separate particles already acceptable for use. Figure V-1 shows a typical hammer hog. Such a unit capable of handling 15 tons per hour would cost about $10,000 (less motor). Disc screens (see Figure V-2) are proportionately much less expensive, with a unit having a 120-tons-per-hour

Figure V-1

HAMMER HOG

(Courtesy Jeffrey Mfg. Div., Dresser Industries)





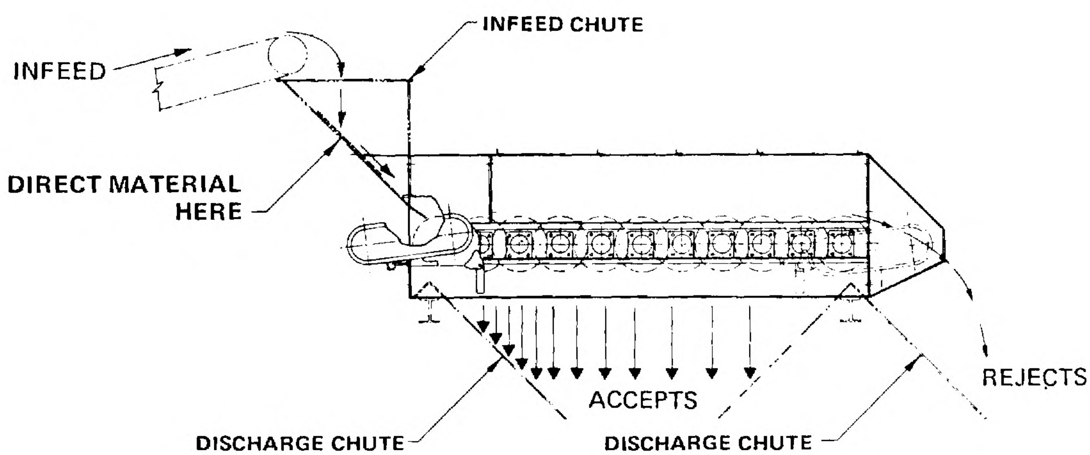


Figure V-2

DISC SCREEN

(Courtesy Rader Systems Inc.)

capacity running about $20,000. A complete system to handle 120 tons per hour could cost in the vicinity of $100,000. Hogs can be considered fairly high maintenance equipment items due to frequent replacement requirements for hammers and knives.

Another consideration in preparing wood residue for use is the separation of tramp metal. Sawmill carriage links, pieces of saw blades, beverage cans, and other foreign metallic material can find their way into wood residue and must be removed before sizing to protect the knife blades or hammers of the hog. Magnets and metal detectors are commonly used in conjunction with conveyors to accomplish this end.

Wood Drying

As shown in Appendix D, the drier the wood fuel, the higher the heating value per pound. When fired in a boiler, the drier fuel will cause increased boiler output (per pound of fuel input) and more complete combustion of the fuel, as well as faster response to steam load changes. With such potential benefits, it should prove worthwhile to investigate current wood-drying technology.

"Green," or freshly cut wood, generally has a moisture content of about 50%, on a wet basis (see Appendix D). The extent to which green wood chips can be economically dried depends, at least to a degree, on the size and configuration of the chips. Whole-tree chips are variable in size, depending upon the particular machine used, the tree species involved, and even the season of the year. The product contains many small particles, arising from leaves, needles, and twigs, as well as larger pieces derived from the solid wood. Some chippers have diverters that route the material from the top of the tree into a separate van or onto the forest floor. They are used when the chip product is intended for use as pulping raw material and bark and leaf contaminants must be minimized. When these diverters, or separators, are not used, the product is sufficiently variable that drying for use as fuel does not occur uniformly.

On the other hand, drying of chips destined for use in particleboard is an established commercial operation. These chips are prepared differently and are uniformly thin, broad, and of the same general size. As a result, standard whole-tree chips and bark residues from debarking operations can readily and economically be dried to 25 to 35% moisture content (M.C.), whereas particleboard chips can be reduced to the 8 to 10% range (wet basis).

Drying green chips to 25% M.C. or so, then, can be accomplished with little difficulty and is more efficient than drying to very low moisture levels. It should be noted, however, if wood chips are intended to fuel a gasification process, that most gasifier manufacturers recommend (if not require) moisture contents no greater than 10 to 15%. (There are, however, three firms aiming at gasification of undried wood waste. See section on Wood Gasification.)

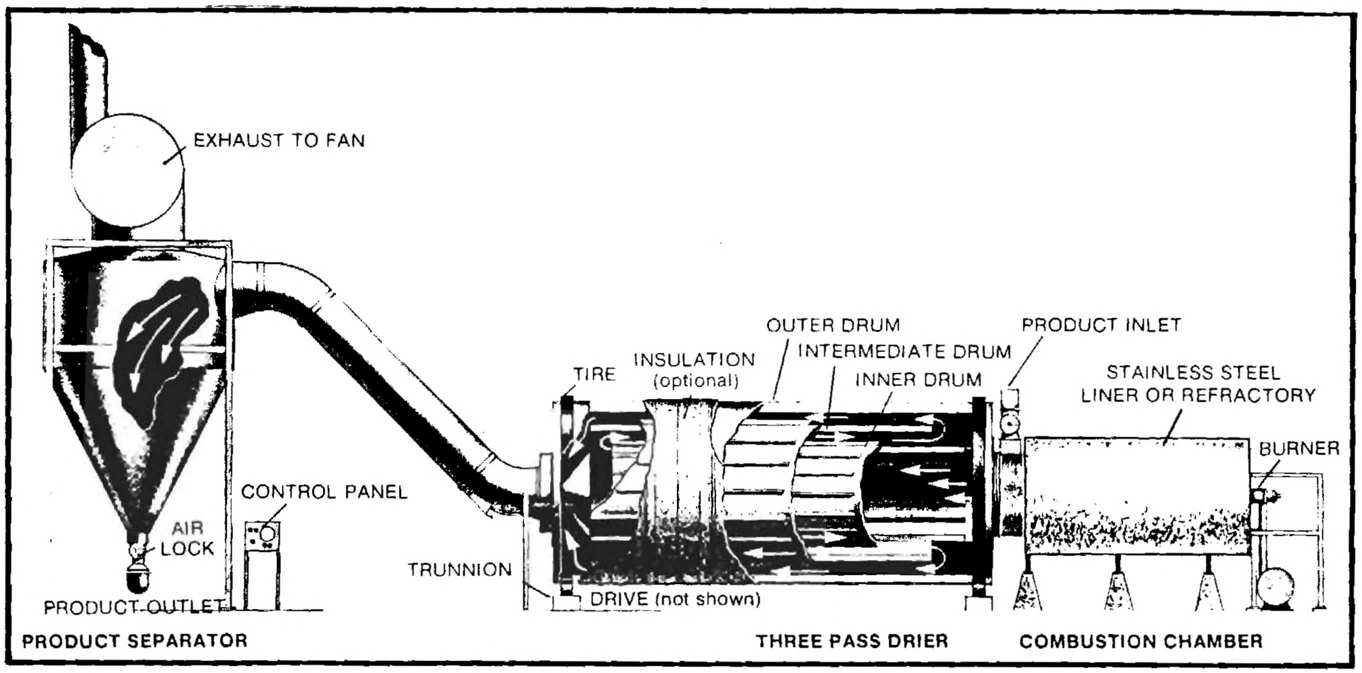
The rotary dryer (see Figure V-3) is one of the primary types in use for drying wood residues. Experience with drying whole-tree chips in such units has shown results that agree with general comments made earlier; that is, fines dry to about 10% M.C. while larger pieces end up in the 22 to 25% vicinity.

Most rotary dryers used in wood drying are of the co-current flow type. This flow pattern has the wood particles and hot gas both moving in the same direction. While counter-current flow of the hot input gases is theoretically more efficient, in applications with wood this approach tends to produce greater quantities of blue haze, a type of air pollution. This occurs when already thoroughly dried small particles are further heated by the hot input gas, thus leading to pyrolysis of the particles' surfaces.

Figure V-3

ROTARY WOOD DRYING SYSTEM

(Courtesy Aeroglide Inc.)



There are two basic types of rotary dryers, the single pass and the triple pass. The single pass comes in two variations: the open center and the center fill. In the triple pass all material passes through three shells. Heat is provided at the feed end. The lighter, smaller, more easily dried particles are more readily moved by the co-current flow of heated air and thus are in the dryer a shorter time. The single-pass units have a larger diameter in the center section, thus providing a longer dwell time for heavier, slower drying particles.

Another type of dryer, which has been used in sawdust drying, is the suspension dryer. The material is dried by hot air while being transported in a sloping or looped tube. The dwell time in this type dryer is only a matter of seconds, so the wood particles must be very finely divided. Suspension dryers also are used in drying previously "fiberized" wood for particleboard manufacture.

Apron-type dryers also have been used for wood drying. In these units the material is carried on a porous belt, while the drying gases are passed through the belt and mat of material to be dried. The principal disadvantage of such dryers is that the wet material is not tumbled or stirred, so channels form through paths of increasingly less resistance to gas flow as the material is conveyed and drying proceeds. Uneven drying can result.

Another category of dryer is the screw conveyor dryer. In this unit, the trough of the screw conveyor is perforated, and drying gases pass through the waste as it is moved forward.

A representative triple-pass rotary dryer capable of handling 300 tons per day of green wood chips (12 foot diameter, 42 feet long) would cost about $225,000. This would include all motors, a gas-oil burner, fans, and a cyclone. Given uniform chips approximately 2 inches by 2 inches by 1/4 inch thick, this unit should achieve an average 10% moisture content. It is designed to use input combustion gases blended with air at about 800°F with an outlet temperature of 250°F. If a wood-burning system were substituted for the gas-oil burner that heats the dryer, this would cost about an additional $60,000, including necessary hoppers, metering equipment, and combustion devices.

In summary, for most applications of wood as a fuel, sizing (grinding or hogging) and drying are desirable steps. They enhance both handling and combustion characteristics.

Wood-Fired Boilers

Wood was the original fuel for steam production in this country. Early industrial boiler plants all ran on wood; coal began to make serious encroachments on the use of wood fuel in the late 19th century. The use of wood fuel became almost a lost art. Coal, in turn, was discarded by many industrial boilers in favor of fuel oil and natural gas.

Recently, of course, there has been a resurgence in coal used for boiler fuel. Wood also has been receiving more attention, although applications of new boilers and new combustion systems for wood have often spun off from similar developments for handling coal.

The pulp and paper industry has been involved in much of the new pioneering effort in wood burning. The last 50 years has brought the gradual but steady development of wood-burning boilers from primitive pile burners to units capable of producing 400,000 to 500,000 lb/hr of steam at pressures that rival those found in central utility plants. This section is more concerned, however, with smaller boilers that could find widespread applications in the non-forest products industries.

Boilers may be divided into two general classes -- firetube boilers and watertube boilers. In the former, as suggested by its name, the hot combustion gases pass through tubes submersed in the boiler water. Figure V-4 illustrates several typical gas flow patterns. The reverse is true for the latter type of boiler: the combustion gases pass over tubes which contain water; as the boiling proceeds, a natural water circulation pattern is established within the tubes (see Figure V-5).

Generally speaking, firetube boilers are more useful in light and medium industrial applications. They are normally less expensive than a correspondingly sized watertube boiler, and they can be more forgiving in terms of routine maintenance, especially with regard to water treatment. Their limitations surface in the 20,000 to 25,000 lb/hr range, particularly when pressures exceed 250 psi. Larger shell diameters require thicker end plates, and beyond the above output and pressure range it is generally not feasible to increase the size and thickness of these plates. The steel watertube boiler is more suitable for large capacities and high pressure due to its smaller component sizes and ability to accommodate expansion.

Besides the firetube and watertube classifications, boilers can be described as "package" or "field-erected." These categorical designations can cause some confusion since virtually all wood-burning units require some field erection. A package boiler can usually be shipped overland by normal transportation methods, such as flatbed truck or railcar. The major boiler components are in one assembly and can often be lifted directly onto a simple foundation and linked (piping, etc.) to an existing system. The package boiler, as a result, requires a good deal less labor prior to start-up than a field-erected unit. The latter often requires individual welding of boiler tubes, as well as the complete fabrication of a steel framework. That is, the boiler is entirely built up at the job site from all its component parts, while the package boiler is nearly complete when it leaves the factory.

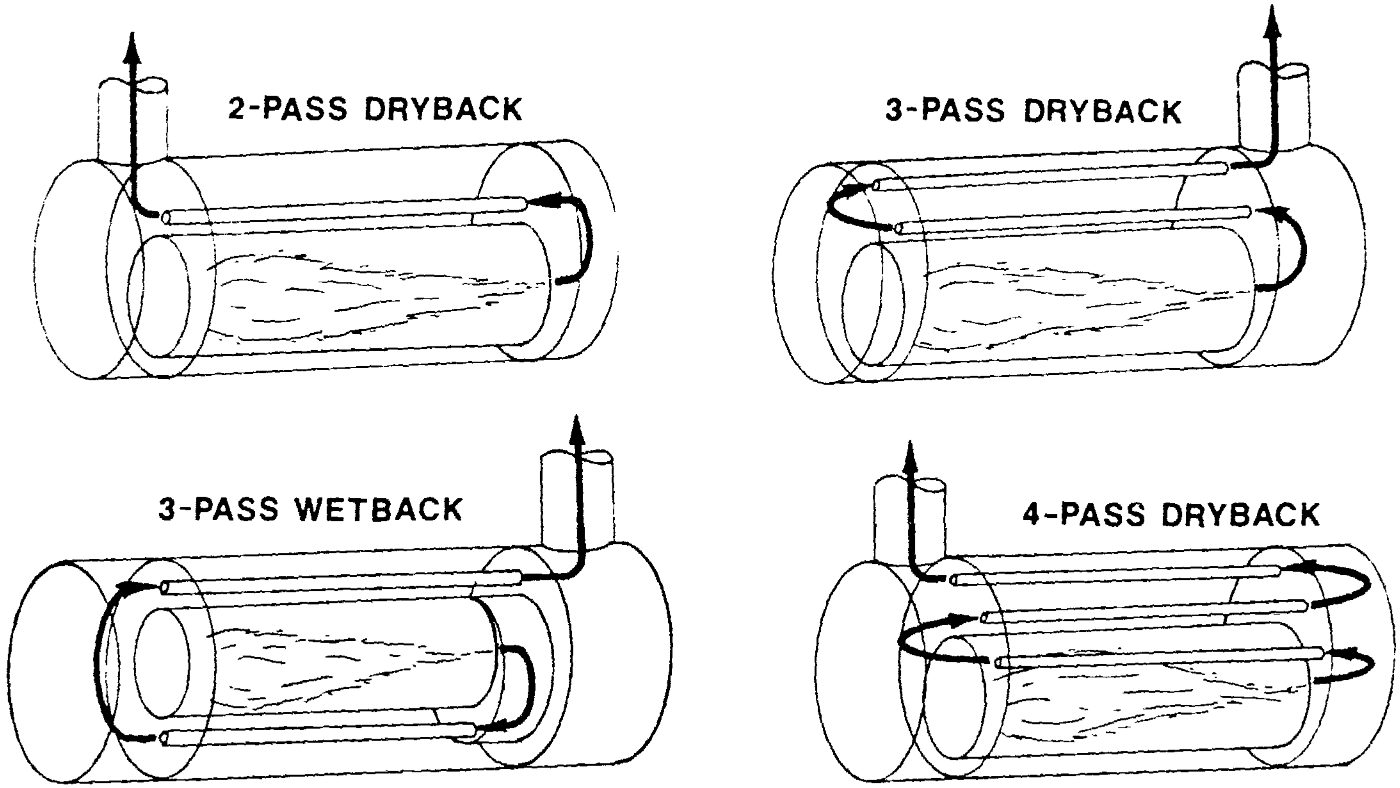


Figure V-4

FIRETUBE BOILER GAS FLOW PATTERNS

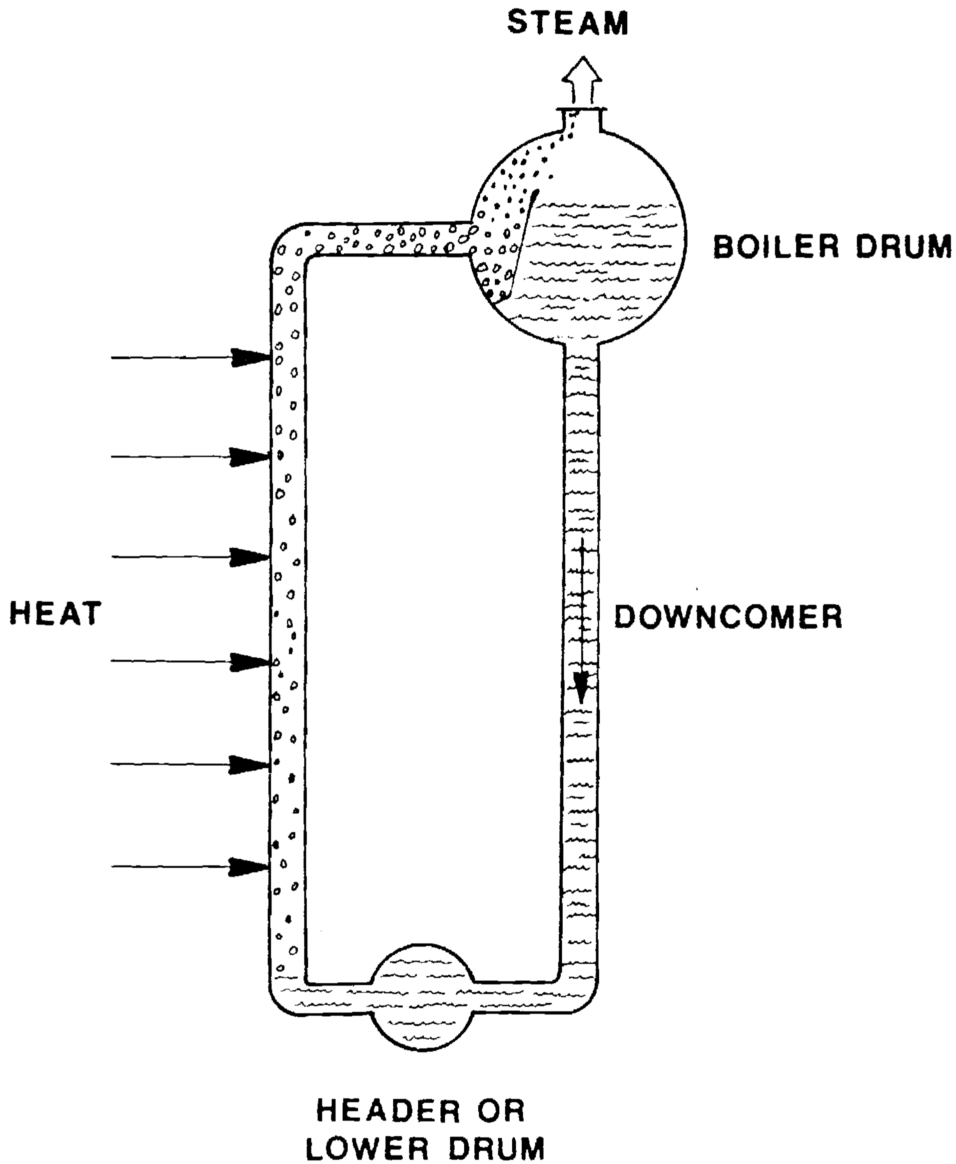


Figure V-5

WATER CIRCULATION PATTERN IN A WATERTUBE BOILER

The American Boiler Manufacturer's Association, in fact, has defined a package boiler as "a boiler equipped and shipped complete with fuel-burning equipment, mechanical-draft equipment, automatic controls and accessories." Package boilers in the 100,000 lb/hr range have been shipped for gas/oil firing, but the larger combustion volume necessary for wood units generally limit the size for a wood-fired package boiler to less than 50,000 lb/hr. As might be expected, field-erected boilers cost more than package boilers, and assembly times are considerably longer.

There are many manufacturers of wood package boilers. In general, the larger and perhaps better known boiler manufacturers have not shown an interest in producing small (less than 50,000 lb/hr) boilers for light and intermediate size commercial and industrial operations. This gap, however, has been filled quite adequately by a number of smaller manufacturers as wood energy use has expanded, and the market has become quite competitive.

The first cost of wood-burning package boilers can be quite high. For a typical "turnkey" job, including fuel metering, controls, a limited amount of wood-handling equipment, and air pollution control devices, the cost range would be about $28 to $60 per pound of steam for a small (100 h.p. or 3,450 lb/hr) system. As the system increases in size, the range narrows and the cost decreases per pound of steam. A 300 h.p. (about 10,350 lb/hr) system would range from $15 to $40 per pound, while a 1,000 h.p. (34,500 lb/hr) system would vary from $12 to $20 per pound.

The boilers at the low end of these ranges are generally those with the least flexibility with regard to the quality of fuel that can be burned. Even the smallest package boilers require a given amount of solids handling equipment and control systems, so the total cost per pound of steam is considerably higher for these smaller systems. A given wood package boiler will typically have a first cost of three to four times that of a comparably sized gas/oil boiler.

In summary, wood-fired package boilers as a class are considered to be fully commercial. Depending on the type of wood to be used, an industrial customer should be able to receive at least several bids on a complete wood-burning system. Although the initial cost will be substantially higher than a conventional gas/oil package boiler, the payback time resulting from fuel cost savings could prove to be attractive. The majority of these package boilers on the market today are automated, or nearly so, and would require only infrequent operator attention. Most system malfunctions would be likely to occur in the wood-handling system. Nearly all of these package systems will require some kind of collection device to meet local air pollution codes; the potential industrial customer would be well advised to investigate local regulations before entering into a purchase contract. Such a contract should stipulate that the boiler manufacturer guarantee compliance with the air pollution regulations. Finally, a visit to an existing installation similar to that being considered for purchase is highly recommended.

Field-erected boilers, as mentioned above, are more costly than package boilers. Typically, the initial capital cost is in excess of $35 per lb/hr of steam produced. Industrial users with low through medium steam requirements probably will find package boilers more suitable. Many paper mills have large bark-fired or combination (bark plus gas and oil firing) boilers that can produce 400,000 to 500,000 lb/hr of superheated steam for process use and electric power generation. Operating pressures may exceed 1,200 psi.

Virtually all field-erected boilers are of watertube design. Although earlier bark boilers were often equipped with "dutch ovens," or large refractory furnaces in which the bark and wood waste was burned in large piles, advances in stoker equipment made such designs essentially obsolete. Traveling grate or spreader stokers, for example, are now widely used.

Large field-erected boilers require full-time operating crews and a great deal of maintenance. They are usually considered cost effective only in 24-hour-per-day operational situations, since constant startup and shutdown of these units results in refractory damage and insulation cracks. Refractory repairs are usually necessary on an annual basis anyway, and major rebuilds may be required every several years. There are fewer companies manufacturing these large boilers than the previously discussed package units, and the processes of receiving permits and subsequent construction can easily span three to four years. Most wood-fired field-erected watertube boilers utilize wet wood, as opposed to the firetube boilers that normally require dry wood fuel.

Suspension and Cyclone Burners

Utility boilers have made widespread use of cyclone furnaces for burning pulverized coal for a number of years. The fuel is very finely ground and blown into the furnace almost as a gas; as a result, the combustion process is very efficient and fly ash problems less difficult to deal with. Variations on the cyclone furnace concept have been developed for burning wood waste as well, but there are fuel characteristic limitations that can restrict applications of these systems. The wood must be dry (less than 15% moisture content, wet basis) and of uniformly small particle size.

Despite such restrictions, quite a few of these units have been placed in industrial plants, primarily in the forest products industry. They have been used to fire directly into boilers, rotary dryers, incinerators, lumber dry kilns, and veneer dryers. Prices for this equipment vary widely due to site-specific requirements for installation. For units having a heat release capacity in the vicinity of 20 million Btu/hr, for example, the cost range is approximately $60,000 to $200,000. The range is at least partially due to variations in auxiliary equipment included, such as a fuel preparation system, gas/oil firing standby capabilities, controls, fuel meters, fans, and fly ash collectors. Smaller systems have a higher cost per energy unit since they require roughly the same degree of control and wood-handling capabilities as the larger systems.

Individual burners are available with capacities ranging from 5 million to 100 million Btu/hr, with multiple burner installations often utilized. A typical turndown ratio for this class of burner is 5 to 1. Ash removal is required anywhere from every few days to weekly. In some cases, ash carryover could potentially cause product contamination, but a number of units employ an integral ash separation device that reportedly results in a cleaner gas output.

Much work has been done on a variation of the cyclone burner that would be capable of dealing with wet wood (up to 65% moisture content). This unit operates partially as a gasifier in the primary section of its two combustion chambers. Volatiles driven off in this gasification are then combusted in the secondary chamber. These units are quite large; the cost most probably would be somewhat higher than for a gasifier or fluidized bed combustor with a similar output rating. A continuous automatic ash removal system is a recent addition to this type of unit. Due to the cost, complexity, and size, this "wet cell" burner would not generally be well suited to small industrial applications.

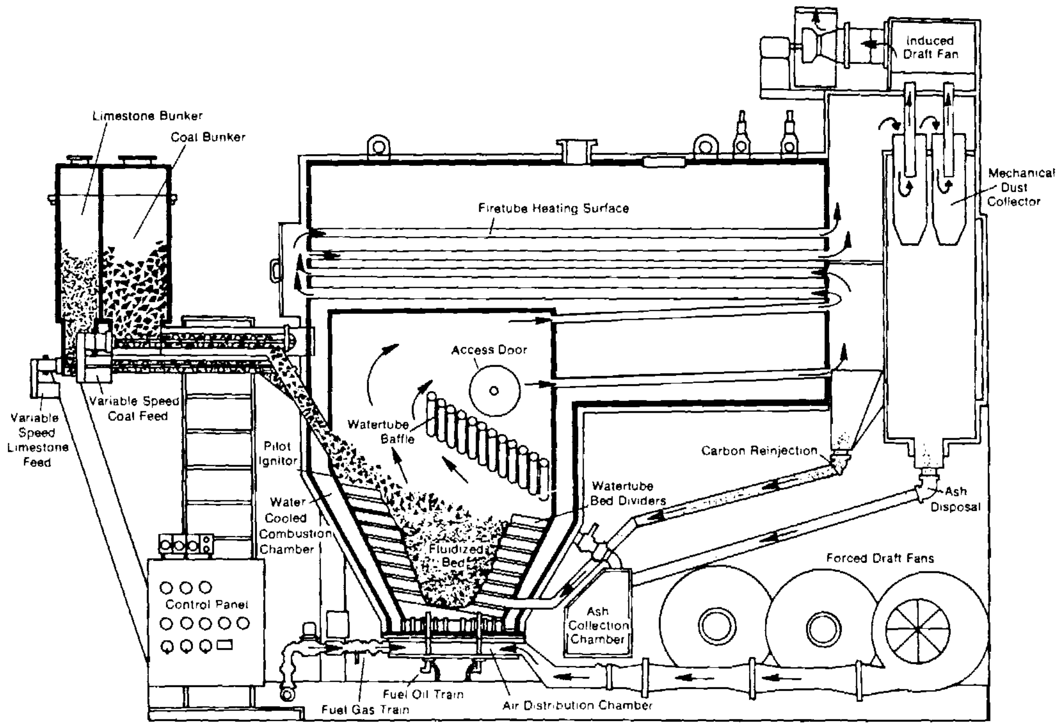
Fluidized Bed Combustors

The fluidized bed combustor has enjoyed considerable publicity over the last several years, especially as an alternate combustion system for coal burning. The basic operating principles are fairly straightforward. The combustion chamber has a porous floor through which combustion air is blown. The "bed" material, most commonly small particles of sand or limestone, rests on top of this floor; as air is blown up through the floor, it bubbles up through the bed material. When it moves rapidly enough, the grains are lifted and held in suspension in a turbulent, "boiling" mass. The fuel could constitute less than 1% of the total bed material, but, as it burns, it makes the inert bed particles red hot. The turbulent mixing action of the hot bed material is quite conducive to complete burning of the fuel; it also keeps the temperature stable, so that the bed does not rapidly heat or cool. Heat is thus transferred within the bed and from the bed material to the surrounding walls or boiler tubes through the direct impact of the hot bed particles. Figure V-6 shows schematically how the fluidized bed is applied to a package boiler arrangement.

Fluidized beds have attracted interest for coal burning because, when limestone is used as the bed material, it reacts with the sulfur in the coal to form a salt that can be removed from the bed. This prevents the escape of sulfur compounds up the stack and can reduce the need for pollution control devices.

Fluidized bed combustors also have shown promise in wood-burning systems as being capable of handling wet and irregularly sized wood fuels. They can discharge into boilers for steam generation or directly into dry kilns, veneer dryers, or rotary dryers. Work has even been done on discharging into a gas turbine for power production, but this concept has not yet been commercialized. In direct heat applications, the ash carried over can be cleaned from the gas with scrubbers or its heat recovered through an air-to-air heat exchanger. Ceramic recuperators have been used for this purpose with conventional combustors, and they could prove to be useful in fluidized bed and pyrolysis applications. This would be of particular

Figure V-6



PACKAGE FLUIDIZED BED BOILER

(Courtesy Johnston Co.)

interest for such industrial applications as drying chemicals where a comparatively clean gas is required. When burning wet wood, combustion gas temperatures in fluidized bed combustors are about 2000°F, so only moderately hot, clean gases could be produced through a heat exchange procedure. Some work has been done with fluidized bed pyrolysis systems, which may have potential for producing cleaner combustion products than the basic fluidized bed.

Fluidized bed boilers are generally available in capacities ranging from 3,800 to 100,000 lbs steam/hr. Most such units are considered capable of burning wood having moisture contents as high as 55 to 60%. Continuous bed cleaning devices are available for most models, often as a separate option. Some sort of air pollution control device, such as a multiclone collector, is normally required.

One point concerning operating parameters should be made. Experience has shown that if sand-bed temperatures are allowed to rise above approximately 1200°F, the bed material will fuse, leaving a solid mass. Applications involving burning municipal waste blended with wood chips also have suggested that a certain amount of glass can be tolerated in the fuel mix if the same temperature limitation is observed.

Costs for fluidized bed systems are generally higher than for wood-fired package boilers of comparable capacity. A 10,000 lb steam/hr unit would generally range from $120,000 to $200,000, depending on auxiliary equipment, such as fuel feed systems, fans, ducts, and pollution control equipment. A 20,000 lb/hr unit would similarly have a likely cost range of $200,000 to $350,000.

In summary, fluidized bed combustors have the demonstrated advantage of being able to burn wet wood. Their cost is somewhat higher than more conventional systems, and they normally would be considered to require more maintenance and attention to operation. This is a still-developing conversion technology that definitely bears watching for utilizing wood fuel.

Pyrolysis Systems

Pyrolysis is the use of heat to decompose organic material, such as forestry and agricultural products. Pyrolysis differs from direct combustion in that "burning" is accomplished in the absence of oxygen. The intense heat, ranging from 1100° to 2200°F depending on the process, causes both a physical and a chemical decomposition. In practice, pyrolysis units often use small amounts of oxygen to support the process, but this is typically only about 5% of the level necessary for direct combustion.

The products of pyrolysis include carbon char, pyrolytic oil, combustible gases, and water containing soluble organic compounds. The relative proportions of the products, or yield, are varied by controlling the type of feed material and regulating parameters such as bed temperature and rate of char recirculation. Indirect sources can supply the necessary heat for start-up, but it is generally more efficient to use part of the feed material as the fuel. After absorbing a small amount of heat to initiate the process, the pyrolysis action is self-sustaining.

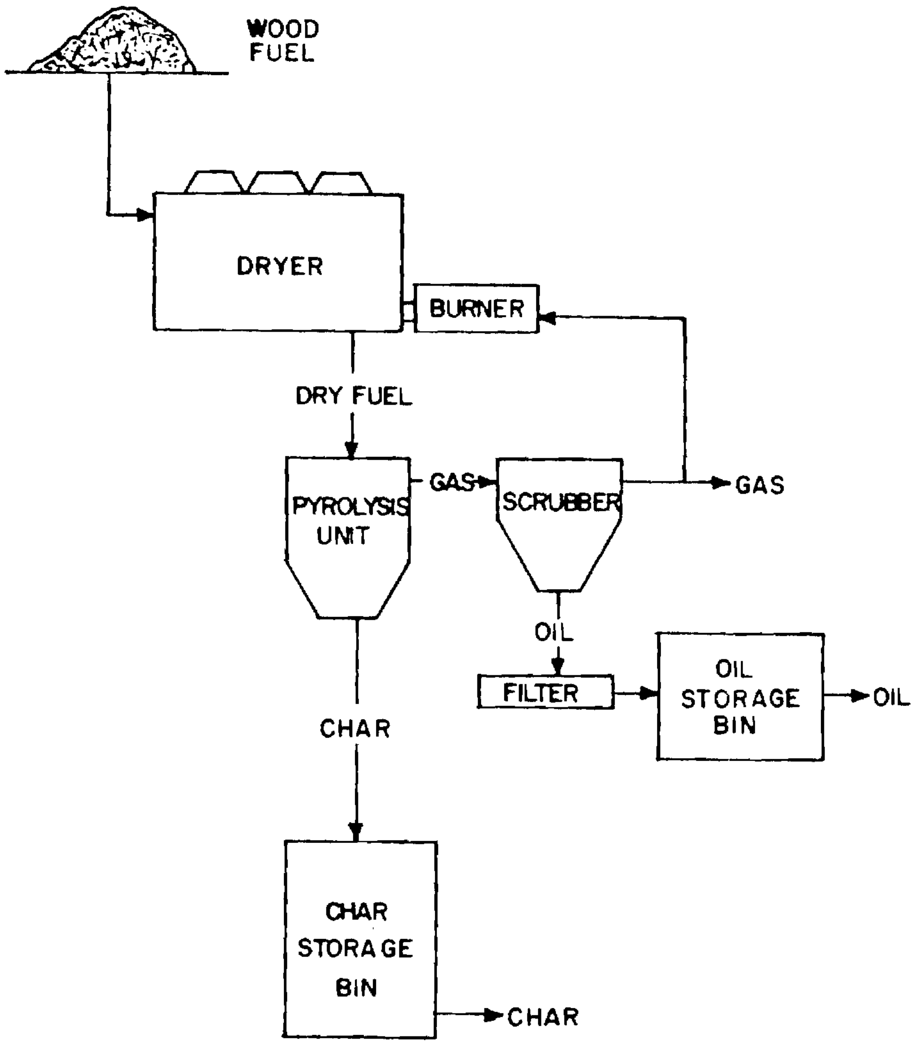
Most of the developmental work on pyrolysis was originally motivated by a need for environmentally sound methods of waste disposal; solid waste is reduced to a fraction of its original volume. The process also has a real potential for fuel production. Energy content of the products depends, of course, on the feedstock, but, in general, the heating value of the char ranges from 12,300 to 13,500 Btu per pound. The heating value of the gas produced by pyrolysis normally ranges from 3,200 to 4,500 Btu/lb; the heating value decreases as the char yield increases. At low char yields, the heating value will generally be on the order of 225 Btu per actual cubic foot (at 200°F with 30% moisture content by weight), as compared with slightly over 1,000 Btu per standard cubic foot for natural gas. Pyrolytic oil has a typical heating value of about 9,000 Btu/lb, which is approximately 90,000 Btu per gallon, or in the neighborhood of 60% of that of No. 6 fuel oil. This oil has, in fact, been mixed successfully with No. 6 oil.

The pyrolysis process generally requires a dry feedstock (7 to 10% M.C.), so that a dryer is normally considered an integral system component. Figure V-7 presents a typical wood waste pyrolysis system, illustrating the derivation of the various products. To date, the prime use for char has been in the manufacture of charcoal briquettes. In addition, it has fuel value as a low sulfur coal extender or substitute and can be used to produce a water grade activated carbon. The pyrolytic oil, in addition to having been demonstrated as a fuel, has potential as a chemical raw material, such as for the production of phenolic resins and rubber tackifiers. The gas produced by pyrolysis is useful as a fuel. It has been used to supply heat to dryers, and preliminary studies have been done on the use of this gas as a fuel for internal combustion engines. Research work has indicated that the heating value of the gas could be increased to around 400 Btu per cubic foot. Process modifications that would be required include removing all of the condensible fractions from the gas and reducing or eliminating the process air.

As mentioned in the previous section, considerable work has been done on fluidized bed pyrolysis. In this application, the feed material is introduced into the fluid bed and partially entrained and carried out of the fluidized bed. These solids contain char particles that are separated from the gas stream with a multiclone. The char collected in this manner can then be recycled to the fluid bed to produce a higher yield of gas and oil, or it can be removed and sold as a feedstock

Figure V-7

WOOD WASTE PYROLYSIS SYSTEM



for charcoal briquettes. The oil contained in the gas stream can be recovered by condensation or sent along with the gas to be used for process heating. The claim is made that this system can handle wood with moisture contents up to 60%, although a fuel in the range of 10 to 15% M.C. is preferred.

There is another class of device, known as starved air incinerators, that should receive brief mention. These were generally designed to generate heat from wet unprocessed municipal solid waste. Most of these units operate on a batch approach and make use of supplementary fuel when the feed material is wet. Some preliminary work has been done in testing the burning of whole-tree chips in these incinerators, and the indications are that it can be done successfully. However, it is considered likely that the system cost would be higher than for fluidized bed combustors designed to use wet wood waste as fuel.

There is little in the way of cost data available for wood pyrolysis systems. The units under development are still largely in the prototype stage and really cannot be considered completely commercial. Since the systems tend to be rather complicated, however, they can be considered relatively expensive.

Wood Densification

Interest is increasing in processes that densify wood and other biomass. The advantages of densified over standard wood fuel are more uniform size, higher energy density, and lower moisture content. Raw wood chips (undensified) at 50% moisture content have only one-third of the energy density of an average coal on a weight basis and one-fourth of coal's energy density on a volume basis. Densified wood, by comparison, has a moisture content of 8 to 10% and two-thirds and three-fourths the energy density of coal on a weight and volume basis, respectively. Densified wood fuel can be shipped greater distances economically due to its decreased bulk and loss of weight during the drying process.

A number of different approaches to densifying are being carried out commercially. These include pelletizing, cubing, briquetting, and extruding.

Densification as a process is dependent on temperature, pressure, and moisture. Wood is largely composed of cellulose, which is held together by lignin, a type of natural adhesive. This lignin becomes soft when heated near 100°C or so, and wood may then be shaped. For this process to proceed satisfactorily, the feedstock should be maintained at a moisture content within the range of 10 to 25% with 15 to 20% considered optimal; this minimizes the pressure requirements and correspondingly the required energy input and resulting wear and tear on machinery (primarily die wear).

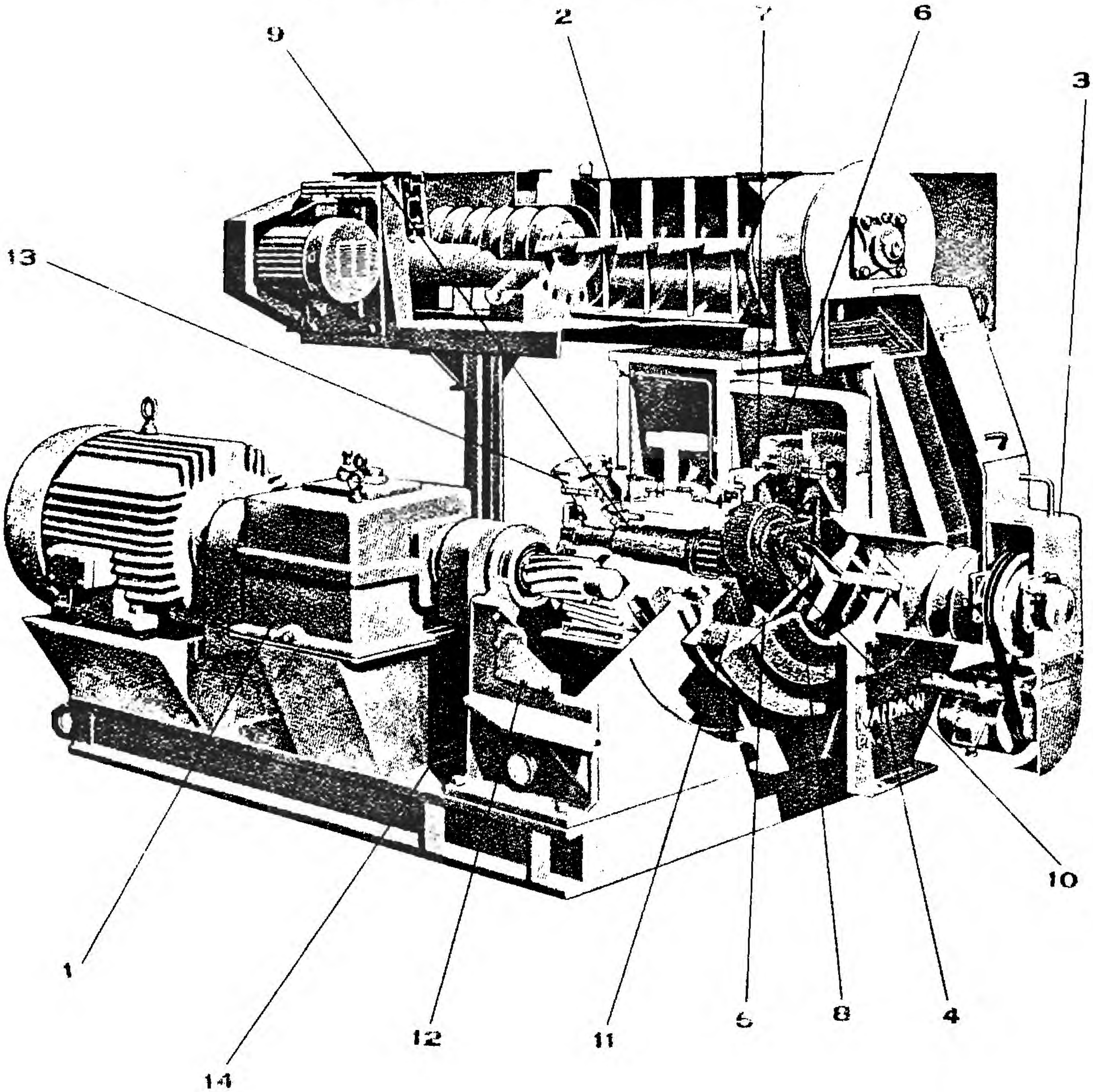
There are several manufacturers currently offering equipment that will produce pellets of densified wood. Figure V-8 shows a typical pellet mill. This type of rotary pellet mill forces the prepared feedstock through a set of dies that form the wood into the desired cross-sectional shape (generally circular). The die is normally hardened steel that has been perforated with holes that may range from 1/4 to 1/2 inch in diameter. As illustrated in Figure V-9, the die rotates against pressure rollers, generating pressure in the area of 10,000 psi. The densified material is thus extruded through the die holes and broken off at the desired length.

The major problem in pelletization is die wear. Depending on the particular equipment and condition of the feedstock, a cost of $2 to $3 a ton is considered fairly realistic for amortizing die replacment costs, although this figure may be reduced as dies improve and operating experience is accumulated. Foreign material in the feedstock, such as sand, can greatly accelerate die wear and push the die cost per ton beyond the above range.

Figure V-8

PELLET MILL

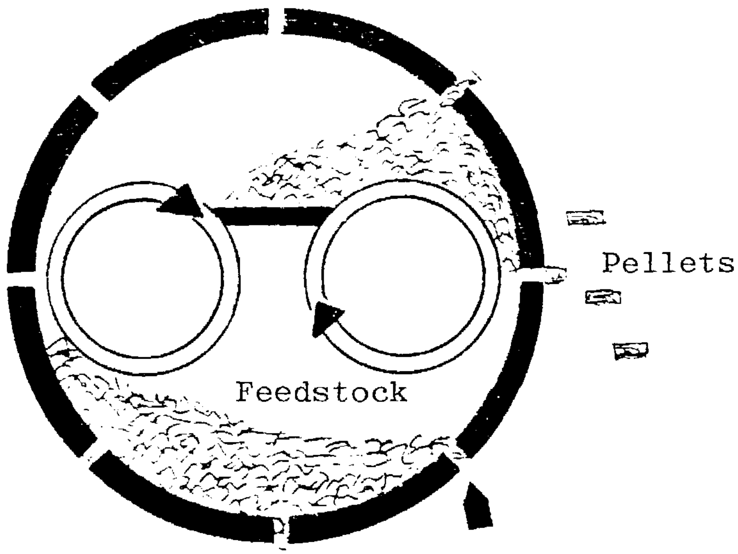
(Courtesy Sprout-Waldron)



1. Transmission	8. Die Stiffener
2. Feeder-Conditioner	9. Main Shaft
3. Distributor	10. Roll Assembly
4. Casing	11. Pelletizing Cartridge
5. Feed Plow	12. Gear Casing
6. Die	13. Shear Pin Protection
7. Die Bolt	14. Lubrication System

Figure V-9

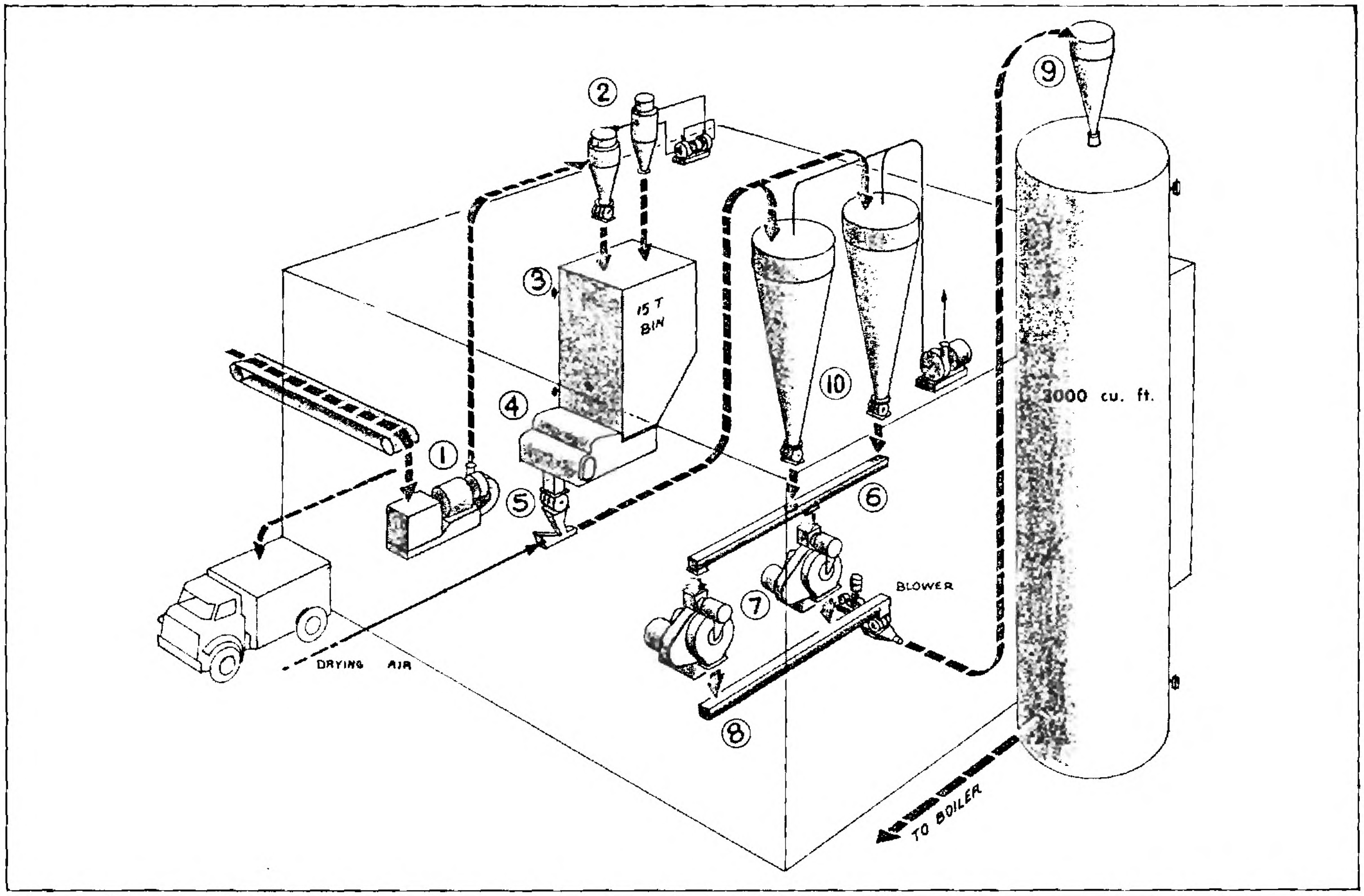
PELLETIZING PROCESS



Pelletizing rates will vary depending on the equipment and feed materials. A 300 horsepower pellet mill should be able to produce at least five to six tons of pellets an hour, with manufacturers claiming 50 to 85 pounds per horsepower per hour. A typical pelletization plant having a 300-ton-per-day capacity would cost in the vicinity of $2 million. Figure V-10 illustrates a representative wood pelletizing operation. Although this includes only two mills, whereas the 300-ton-per-day plant would most probably have three, it helps to explain why such a high cost is involved; that is, a significant amount of hardware is necessary to prepare the feedstock for the pelletizing process.

"Cubing" and "briquetting" often have been used synonymously, although, strictly speaking, cubing is really only a variation of pelletizing that produces larger cylinders or cubes, 1 to 2-inches across. Briquetting, on the other hand, by strict definition compacts the feedstock between rollers with cavities, which produces pieces of densified material shaped like charcoal briquettes. A number of machines are identified as briquetters, however, that produce logs or discs from about 2 to 3 1/2 inches in diameter. A typical model of this type is shown in Figure V-11. It uses a ram to force the feedstock through the die, after having been fed into a compression chamber. This type of unit can produce discs or wafers 1/2 to 3/4-inch thick, or continuous logs, depending on the type of ram face used.

The extruder uses a rotary screw to force feedstock into a die, forming cylinders anywhere from 1 to 4 inches in diameter. Figure V-12 is a schematic of a typical extruding device. In this model, the screw compresses the feedstock, which is then fed into a prepressure chamber. Here the material is forced against a rotating spiral die



1. Sprout-Waldron Hammermill
2. Sprout-Waldron Pneu-Vac
3. Surge Bin (15 ton)
4. Heil Forage Feeder
5. Airlock
6. Distributing Conveyor
7. Sprout-Waldron Pellet Mills
8. Collecting Conveyor
9. Sprout-Waldron Pneu-Vac
10. Sprout-Waldron Pneu-Vac - Flash Dryer

Figure V-10

TYPICAL PELLETIZING PLANT

(Courtesy Sprout-Waldron)

Figure V-11

BRIQUETTER

(Courtesy Agnew Environmental Products)

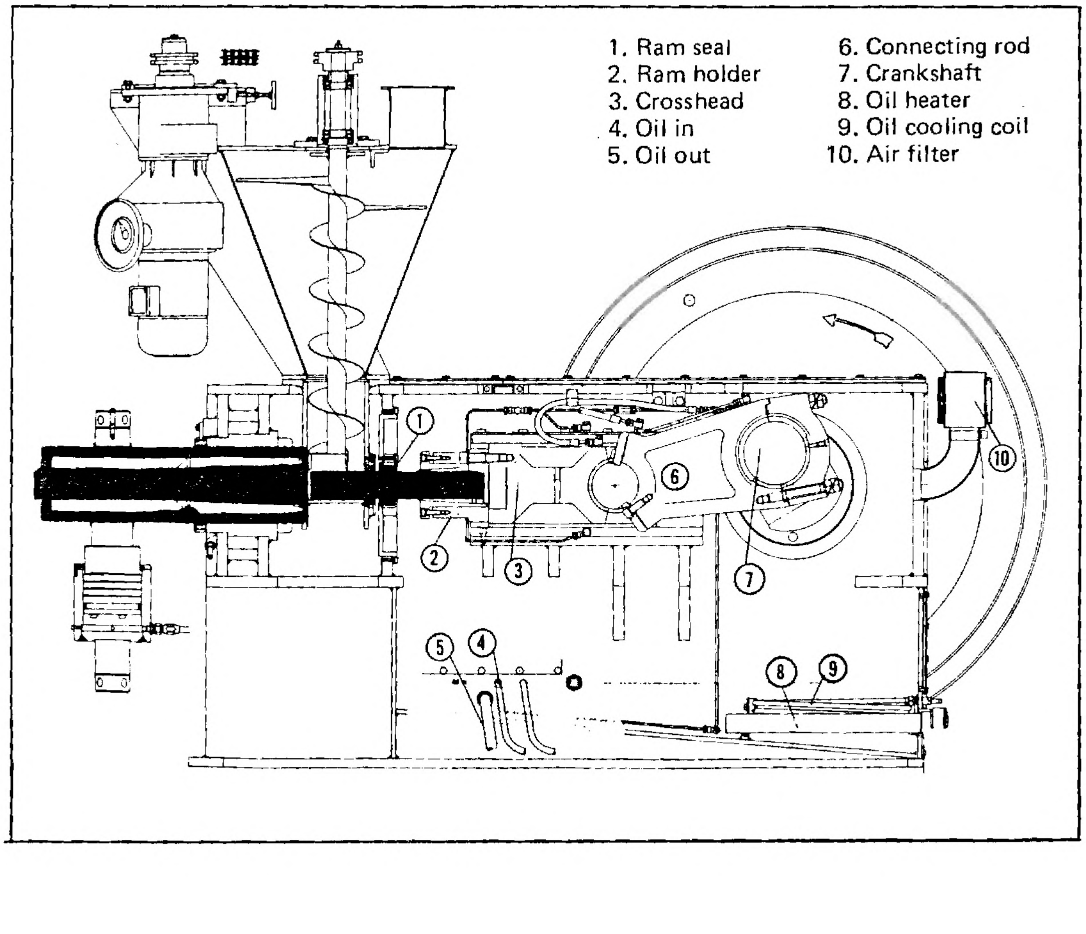
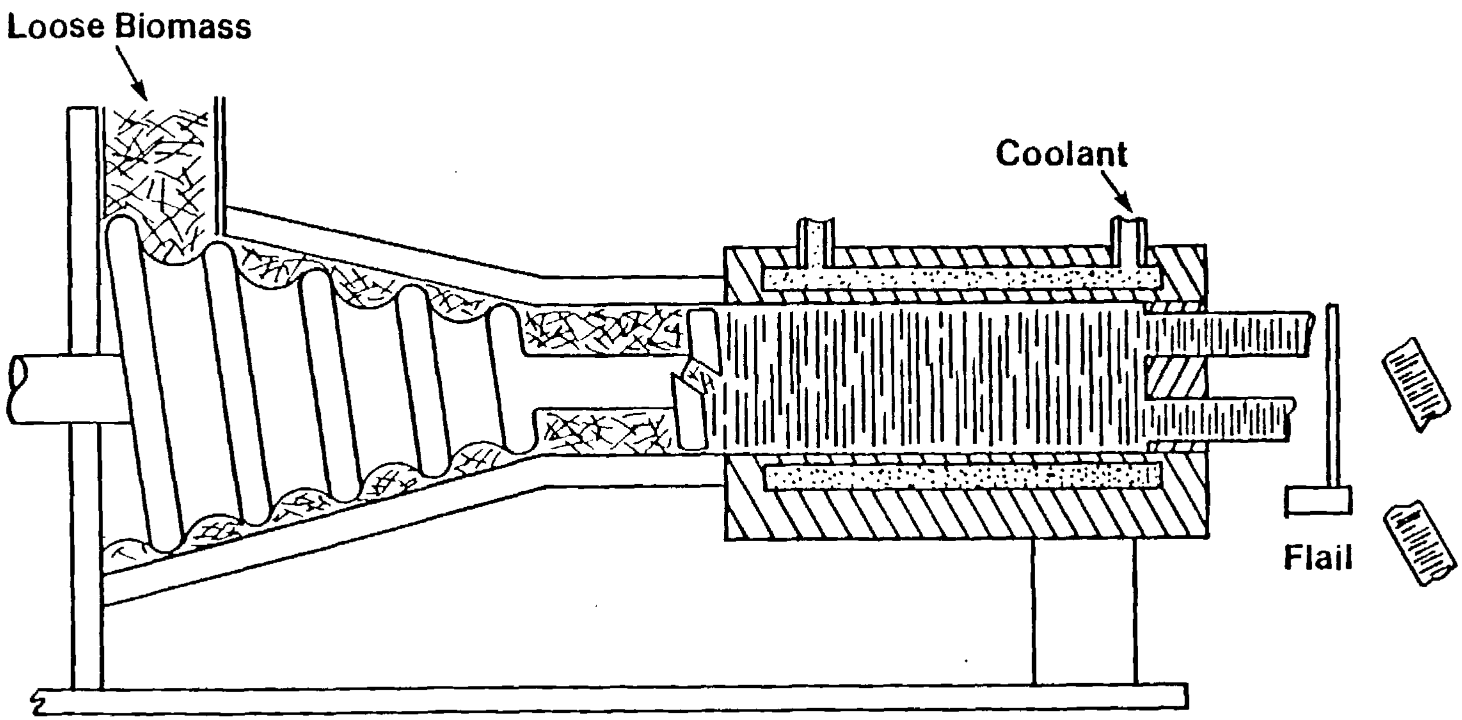


Figure V-12

EXTRUDER

(Courtesy Trans-Arctic Air Ltd.)



head which shears a slice of the compressed biomass. The material is then passed into the die chamber, where it is extruded and cut to length by a rotating flail.

Densified wood shows a good deal of promise as an industrial fuel, both for direct combustion and gasification. Certainly the low sulfur contents of the various densified wood products would be attractive to industries faced with investing large sums for air pollution equipment. Densification has particular merit when wood is to serve as an alternate to lump coal in stoker-fed systems and as a raw material for gasification.

Densifying wood does add cost to the fuel product. Green whole tree chips might sell for an average of \$10 to \$15 per ton, while wood pellets would typically cost \$30 to \$35 per ton to purchase. With the differential in moisture content and energy density, however, on a per million Btu basis, chips (at \$14/ton) would cost \$1.55 and pellets (at \$30/ton), \$1.85. The energy requirement for densifying wood has been estimated at approximately 7% of the energy in the feedstock: about 5% for preparation (drying and grinding), and about 2% for the actual densification.

Wood Gasification

Gasification is the term for the thermal conversion of a solid fuel (e.g., biomass or coal) to a gaseous fuel that can be used to produce heat or power, or in chemical synthesis. It is not a new concept, but it has generated a substantial amount of renewed interest over the past several years. The first gasifiers were built around 1860, and a steady development continued through the 1940's. Both stationary and portable gasifiers were manufactured to power ships, automobiles, electric power plants, and tractors. During World War II, over 700,000 vehicles in Europe were adapted to run on gas from small attached gasifiers.

Feedstock for these original gasifiers included nearly every conceivable form of cellulose, including wood, coconut husks, rice hulls, and olive pits.

The wood gasification process is basically the same as that used to produce coal gas. Coal gasification has been used for years in the steel industry to produce coke, with the resultant by-product of coke-oven gas. Although gasifiers theoretically can use any carbonaceous solid fuel such as coal, lignite, or biomass, proper operation depends on the design relative to a given fuel as well as the fuel density, moisture, and particle size. Small fixed-bed coal gasifiers are of two types: single stage and two stage. The former have stirrers and remove gases from the top, whereas the latter normally do not have stirrers and remove gases in two stages. Generally speaking, coal gasifiers are more costly and complex than necessary for gasifying densified wood or perhaps dried wood chips. Of the two types mentioned above, however, the two stage probably would be preferable for use with wood, since wood generally has a higher volatile content than coal.

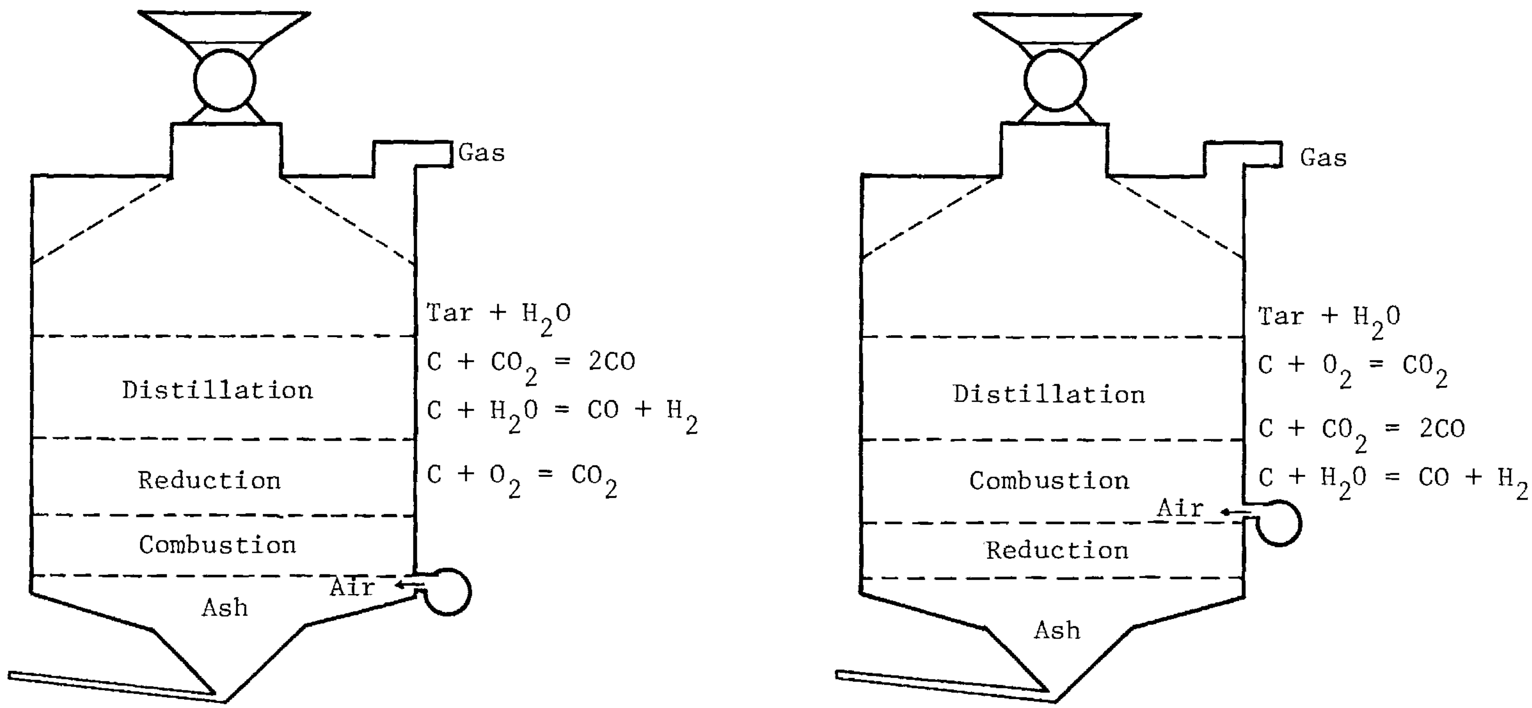
There are many different equipment configurations available for use in wood gasification. The units that are generating the most interest today are the "air" gasifiers. These typically pass about 25% of the theoretical combustion air through a glowing char bed, and several chemical reactions take place that generate a low-heating-value gas in the range of 100 to 200 Btu/ft^3. By contrast, the more sophisticated "oxygen" gasifiers pass pure oxygen through the char bed and yield a gas having a 300 to 400 Btu/ft^3 heating value. These oxygen units are more costly and require additional safety precautions due to the dangers inherent in handling pure oxygen.

Wood gasification has been eyed as a retrofit technology for gas/oil fired boilers. Low Btu burners can be substituted for existing conventional types, and the boiler can then be fired with the "producer" gas generated by the gasification process. Some derating of the boiler would occur; the degree of derating would depend on the particular boiler design.

The term "close-coupled" gasifier describes a system where the gasifier is located on site, and the gas generated in the process is burned in equipment only a few feet away from the gasifier. There are two principal types of close-coupled gasifiers: updraft and downdraft (other models do exist, such as crossdraft and dual-mode gasifiers). Figure V-13 shows cross-sectional drawings of these designs. In the updraft gasifier, air contacts a bed of burning charcoal. This generates hot CO and CO_2 in the reduction zone. These gases then pass through the incoming biomass. In the pyrolysis or distillation zone, volatile gases are given up from the biomass; it is here that materials such as tars and acids are produced. Finally, in the top section, a drying process occurs and the product gases give up some of their heat to the infeed as they exit. In the downdraft gasifier, air is injected into the hottest part of the charcoal fire and is then drawn downward through the charcoal bed. Tars and moisture from the fuel in the higher regions also pass through the bed, generating gases such as CO and H_2.

While the various gasification approaches differ with regard to where the reactions occur, the processes are fundamentally the same. In the case of downdraft gasifiers, however, moisture contents of wood feedstocks are stipulated to be in the 10 to 15% range. These units correspondingly have output ratings in the 10 to 15 million Btu/hr range. On the other hand, updraft gasifiers have been aimed at providing higher output availability (50 to 60 million Btu/hr) and the capability of utilizing wet wood (50% M.C.). So far these units must be classified as unproven when wet wood is used for infeed.

Figure V-13



Updraft Gasifier

Downdraft Gasifier

TYPICAL GASIFIER CONFIGURATIONS

In general, there are four primary barriers to full-scale commercialization of gasifiers. These are: (a) lack of long-term operational experience by current manufacturers; (b) potential problems with burners and piping resulting from tars and other liquids in the gas; (c) slagging of grates due to wood ash; and (d) requirements for operator attention. All of these points are receiving a great deal of consideration from manufacturers, and there are indications that progress is being made in overcoming the various problem areas.

Price, on the other hand, is one of the most attractive aspects of wood gasifiers. Package wood-fired boilers, as discussed in an earlier section, can cost from three to four times as much as a standard natural gas/fuel oil boiler. Especially when a retrofit to an existing conventionally fired boiler is being considered, a gasification system should prove quite economical. The major cost involved with installing a wood gasification system will be associated with the wood handling, conveying, and metering equipment items. Gasification, therefore, has the potential to prove an attractive alternative to the purchase of complete new combustion systems.

Alcohol Production from Wood

Methanol and ethanol are proven liquid fuels for transportation, particularly as alcohol-gasoline mixtures in autos. To reduce foreign oil dependence, much research emphasis has been placed on the use of ethanol produced from biomass crops and residue. Methanol, also known as wood alcohol, is a relatively inferior liquid fuel compared with ethanol. Ethanol has higher Btu content, is less toxic than methanol, is miscible with gasoline, and burns well without major modification to the engine. Also, both the initial capital investment and the size of the plant required to produce methanol are considerably larger than those required for ethanol.

Much of the recent work for the production of ethanol has focused on the use of food-based products such as sugar, corn, and other grains. Wood, corn stalks, and other plant residues, however, are more attractive raw materials since they are not part of the traditional food chain for man.

Production of ethanol from wood is an old concept. Figure V-14 illustrates the process flow diagram. During World War II, a number of such plants were in operation in Europe. As single-product operations, these plants were not competitive with chemical plants based on an abundant supply of cheap petroleum as the feedstock.

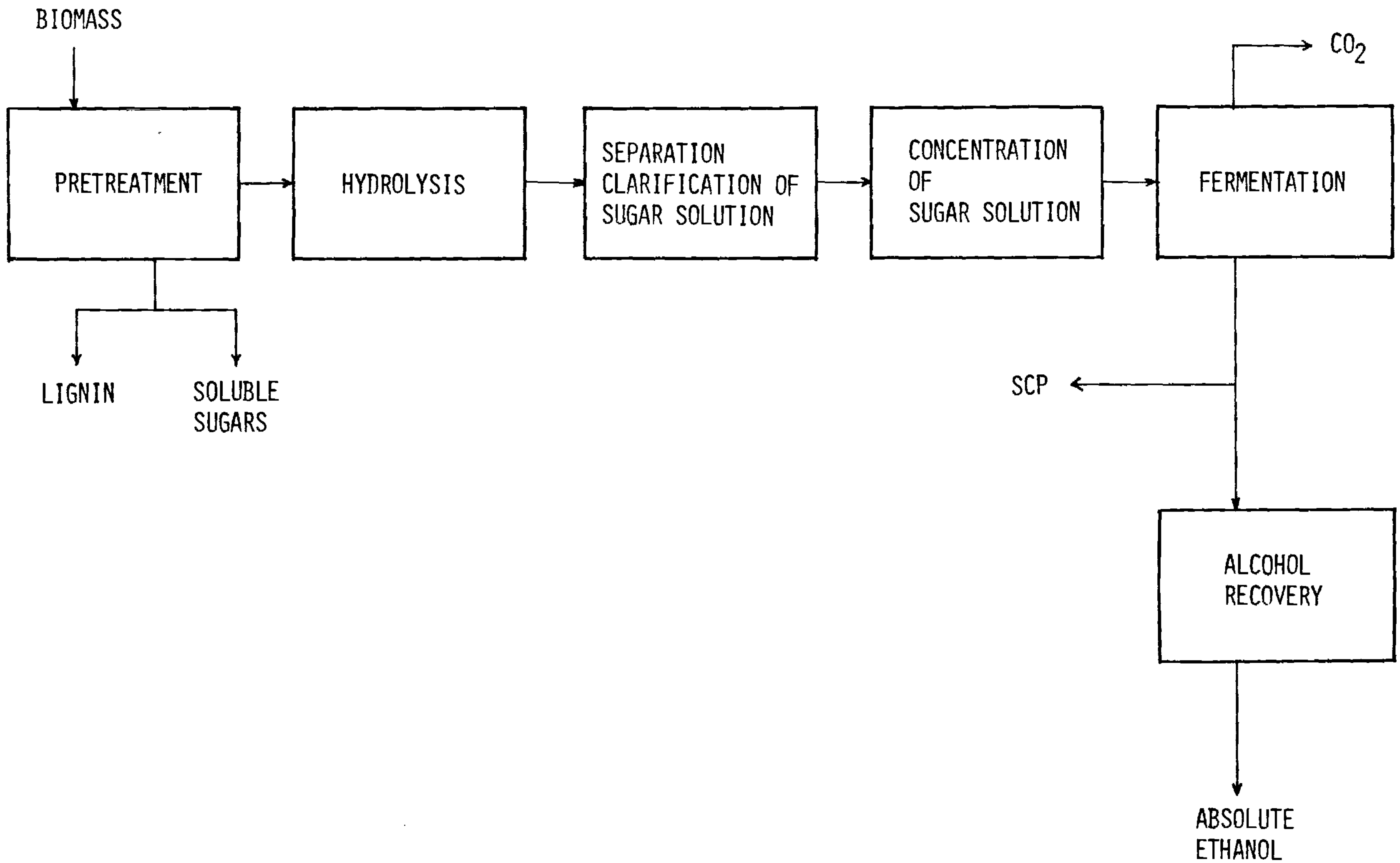
A more desirable approach for producing ethanol from wood is an integrated multi-product plant where all components of wood -- cellulose, hemi-cellulose, and lignin -- are processed, resulting in a number of valuable by-products. Lignin can be pyrolyzed into phenols, char, oil, and a combustible gas. Hemi-cellulose can be converted into pentose and hexose sugars, where the pentose can be used as a starting material to produce furfural, xylitol, single-cell protein, and also, to some extent, ethanol. Cellulose can be hydrolyzed to produce glucose, which then can be fermented to produce ethanol, carbon dioxide, and yeast.

The first stage of operation is pre-treatment, during which lignin is separated from the biomass and hemi-cellulose is hydrolyzed into soluble sugars. The next stage of operation involves hydrolysis of cellulose into glucose, clarification of the solution, and concentration of the sugar solution. The third stage of operation includes fermentation of glucose into ethanol and separation of yeast. The final stage of operation is the recovery of alcohol and the production of absolute ethanol, which can be used in gasohol.

The production of ethanol can be economical only if

Figure V-14

GENERAL BLOCK DIAGRAM OF A PROCESS TO PRODUCE ETHANOL



(1) the raw material is available without large fluctuations in price,

(2) by-products can be sold,

(3) the crude oil price keeps going up, and

(4) liquid fuel becomes less available.

Production of ethanol could play a very important role in reducing the dependence on the foreign supply of liquid fuel.

On the long-term basis, the ethanol produced from the renewable raw materials, such as wood, agricultural residue, and crop residue, looks very promising as compared with high-priced, nonrenewable foreign crude oil.

Equipment for Conversion of Wood to Energy

Numerous manufacturers are actively producing and continually refining the various classes of conversion equipment described in the preceding sections. Appendix E is a representative listing of manufacturers of equipment for densification, handling and processing, storage, and air pollution control; as well as boilers, fluidized bed systems, pyrolysis and gasification systems, and burners. This listing is not necessarily complete or exhaustive.

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VI. WOOD ENERGY APPLICATIONS

Introduction

In order to identify areas where wood energy can benefit the state of West Virginia, it is important to understand how, where, and why energy is consumed in the state. Once this is known, it becomes easier to identify possible areas for wood energy use and also potential quantities of wood energy consumption that are reasonable for the state.

In 1977, nearly 80% of West Virginia's total energy consumption was in the Electric Utility and the Industrial economic sectors. Transportation placed a distant third at 11%. Of the major energy sources, coal was by far the most widely consumed, meeting 68% of the state's energy demand. Natural gas was second, meeting 14% of all demand, and gasoline was third at 9%.

Clearly these statistics indicate that if wood energy is to become important to West Virginia, it must make itself useful in one or more of these areas.

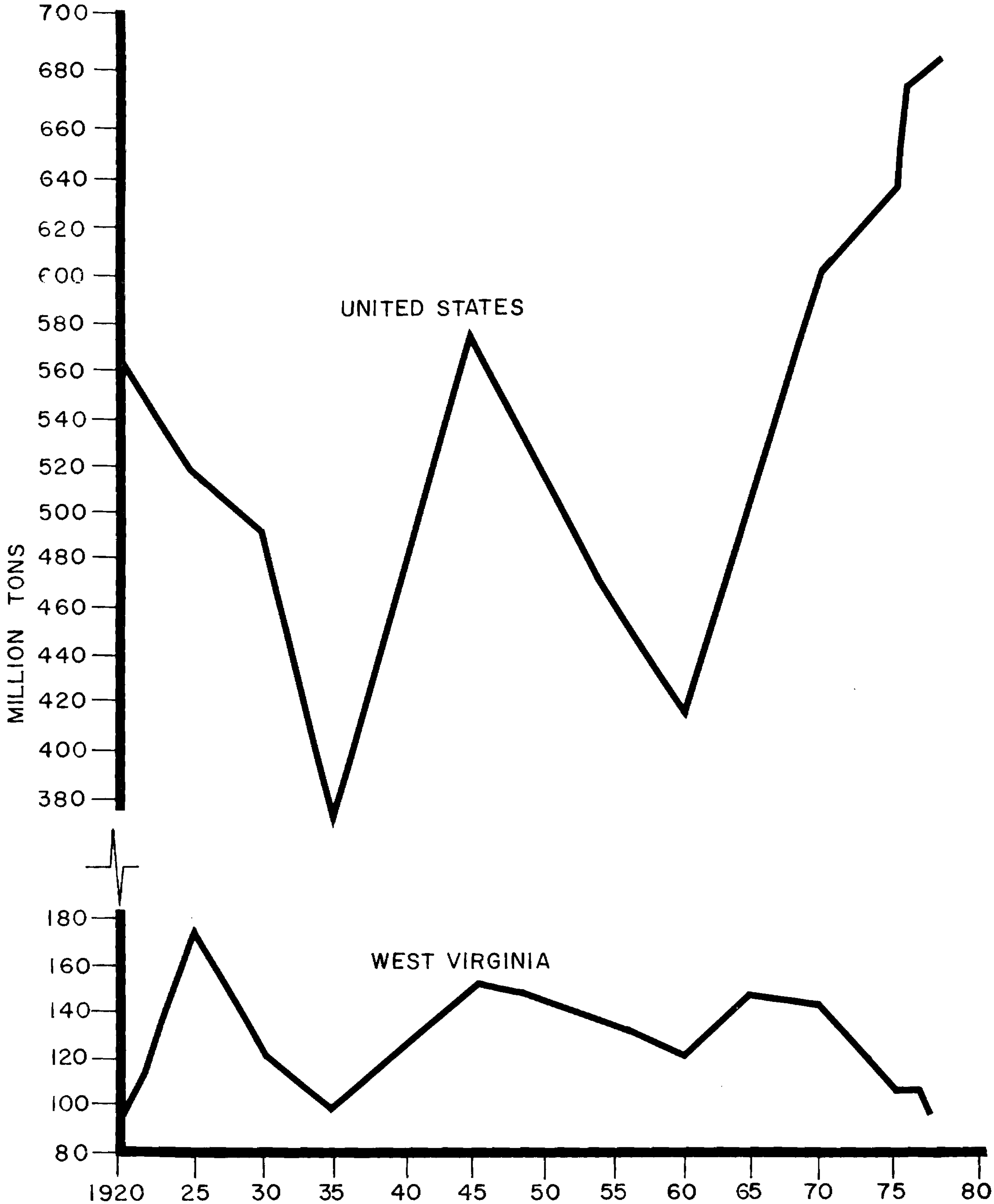
Applications to Increase Coal Usage

Coal is unquestionably a mainstay of West Virginia's economy. Yet for the past 10 years, there has been an almost steady decline in West Virginia coal production, ironically while U. S. coal production has doubled (see Figure VI-1). During this decline, statewide consumption of coal has nearly doubled, almost entirely in the area of electric power generation.

These two facts are important. West Virginia has become a large electricity exporter, selling nearly 70% of its produced electricity to out-of-state consumers in 1974. Further, the electric utility sector of West Virginia consumed half of all of the energy used in the state in 1977, almost all of

FIGURE VI-1

WEST VIRGINIA AND UNITED STATES COAL PRODUCTION



Source: West Virginia Fuel & Energy Office which was derived from coal. With the utilities in the state consuming more and more coal and with total production declining, it appears that an effort must be made to reverse this growing decline in demand for West Virginia coal outside of the state electric utility sector.

While it must be recognized that high grade metallurgical coal sales have been down in recent years and that many other factors are contributing to this overall decline, environmental restrictions on coal usage in certain areas are certainly limiting some of the demand. It is here that perhaps wood can make a contribution.

When coal and wood are blended together, there are certain synergistic benefits obtained environmentally. For instance, a blending of wood and coal in a 1:1 ratio (energy-content basis) can reduce $< 2\%$ sulfur coal to $< 1\%$ sulfur fuel and permit its use in an environmentally acceptable manner. A wood and coal mixture can also allow more effective removal of fly ash than can be performed when coal is used alone, and studies have shown that prepared wood mixes need not require users to derate their coal furnaces. Clearly, therefore, wood can assist coal usage in areas where demand is being curtailed strictly for environmental purposes. However, some additional research will be needed to determine the quantity and cost of the mixture with West Virginia wood and coal.

Industrial Applications

The manufacturing sector is the second leading energy consumer in West Virginia behind the electric utilities. In 1974, 36% of West Virginia's energy usage was by this sector.

Important fuel mix changes occurred in the manufacturing sector during the 1967 to 1974 period. Coal usage over this period is of particular interest. Coal was the only major fuel to decrease in usage in absolute terms during this time span (see Figure VI-2). Residual oil (#6) usage increased most rapidly at an annual rate of 34% from 1971 to 1974, while natural gas showed the greatest total usage increase from 1967 to 1974 (see Appendix F).

Natural gas was the least expensive of the major energy sources in the manufacturing sector from 1967 to 1974. Figure VI-3 reflects the changing energy cost per million Btu for West Virginia's industry from 1967 to 1974. Table VI-1 reflects 1977 and 1979 cost figures for industrial fuels in West Virginia. The 1979 coal and distillate oil prices are representative term costs. Spot prices in these two areas indicate coal prices have temporarily leveled out while distillate oil prices can be expected to increase further.

Table VI-1

WEST VIRGINIA ENERGY FUEL PRICES
FOR THE INDUSTRIAL SECTOR
($/million Btu)

	1977	1979
Natural Gas	$1.92	$3.00
Coal	$1.47*	$1.48**
Distillate Oil No. 2	$3.19	$3.40
Residual Oil No. 6	$2.23	$3.25***
Purchased Electricity	$6.40	$8.20

* Since no value was available for industrial sector alone, this value is the average for West Virginia coal in 1977 (all grades).

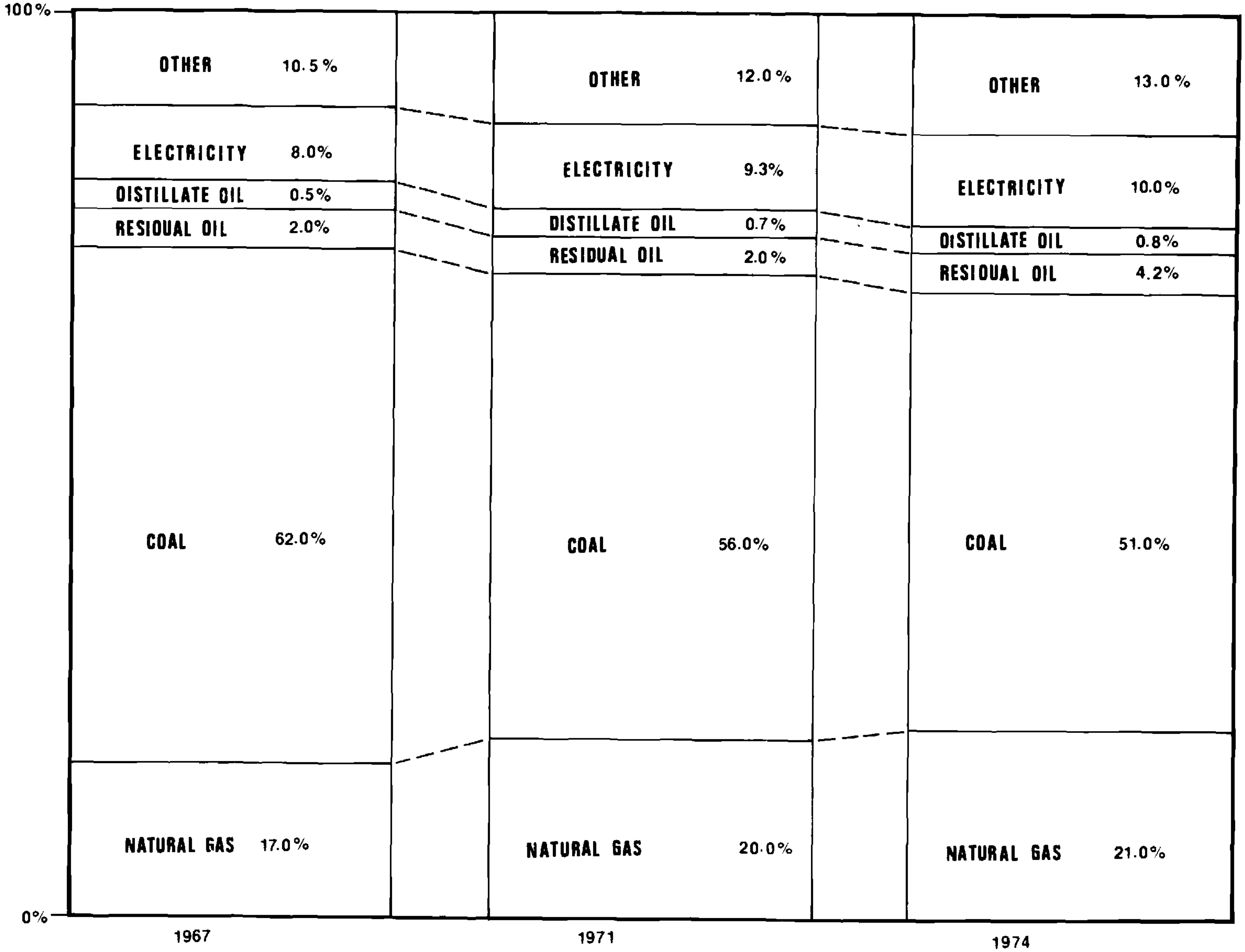
** Steam coal only - price reflects an average term cost for 0% to 2% sulfur grade.

***Average cost of both 1% and 2% sulfur grade

Source: West Virginia Fuel and Energy Office

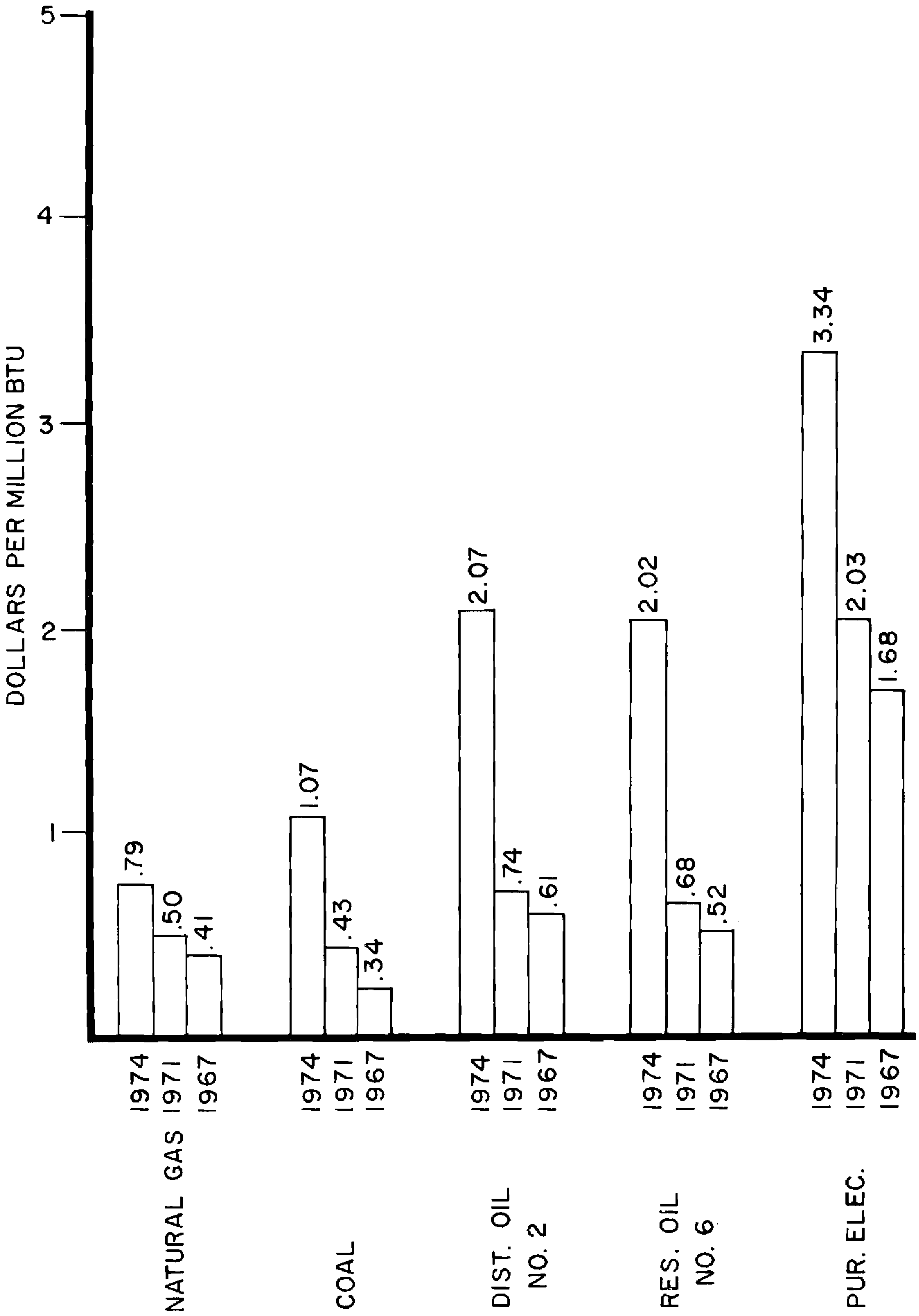
FIGURE VI - 2

ENERGY TYPES USED IN MANUFACTURING IN WEST VIRGINIA



Source: U.S. Department of Energy

FIGURE VI - 3
ENERGY COST FOR MANUFACTURING IN WEST VIRGINIA



Source: U. S. Department of Energy

Nearly 94% of all energy consumed by West Virginia's manufacturing industry in 1974 was in three SIC code industries: Primary Metals, Chemicals, and Stone, Clay and Glass. Table VI-2 shows the approximate breakdown of each industry's consumption by major source. Overall, Primary Metals consumed 47% of the manufacturing sector's total energy consumption. Chemicals consumed 39%; and Stone, Clay and Glass, 8%.

Since the manufacturing sector consumed 40% of all natural gas used in West Virginia in 1974, use of wood as a natural gas substitute should be considered here. Wood substitution for natural gas is particularly attractive because West Virginia has been a net importer of natural gas since 1972 (see Figure VI-4).

The Stone, Clay, and Glass industry of West Virginia consumed most of its energy as direct heat. In cement, direct heat in the form of kilns accounted for 85% of all energy consumed. In the glass industry, most energy was spent in the melting process (50%); and in the lime manufacturing process, over 75% of the energy was consumed in the calcining process.

For the Stone, Clay, and Glass Industry, direct heat accounted for over 55% of the energy consumed. Driving machinery comprised an additional 43% of the energy. Space heat and other uses made up the remaining energy use (see Figure VI-5).

Wood gasification can produce a sufficiently clean fuel to provide both direct heat and machinery drive. It is further possible to produce gases from wood, which, when combusted, have only a slightly larger volume of combustion products than that from natural gas. This fact limits the amount of equipment modification needed to make the substitution of wood for natural gas. However, clean wood gas currently has only one-seventh to one-fifth the heat content of natural gas. Consequently, care must be taken in many retrofit applications since the total process heat output will decline per cubic foot of fuel

TABLE VI-2
1974 ENERGY USE BY MANUFACTURING INDUSTRY

PERCENT DISTRIBUTION OF TOTAL ENERGY BY FUEL TYPE

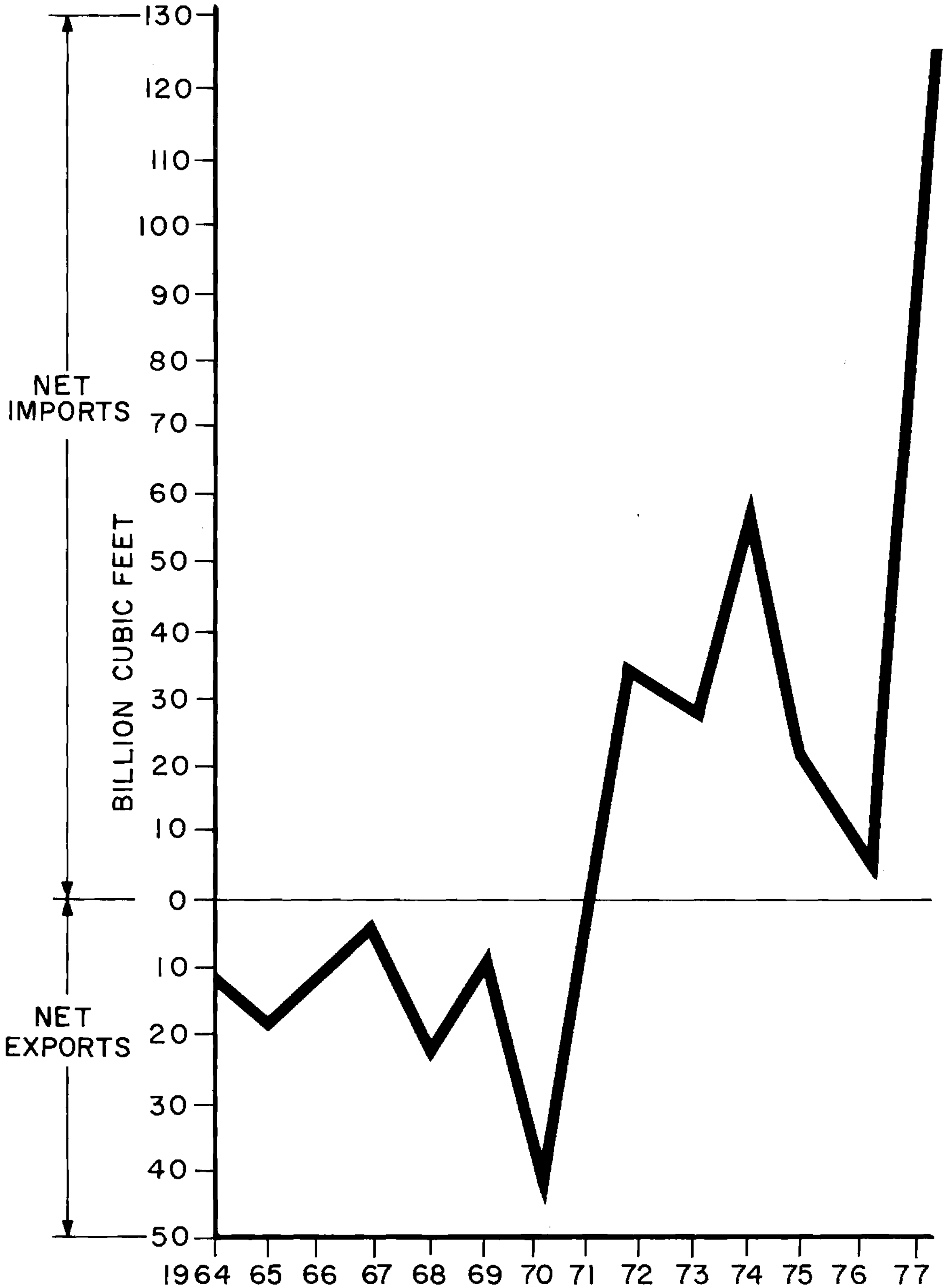
% OF TOTAL MFG. CONSUMPTION	SIC CODE/INDUSTRY	TOTAL ENERGY USE (TRILLION BTU)	NAT. GAS (%)	ELECTRICITY (%)	COAL (%)	FUEL OIL (%)		OTHER (%)
						#2	#6	
39	28 CHEMICALS	153.9	25	9	36	.4	1.5	28.1
8	32 STONE, CLAY & GLASS	31.7	69	7	0	0	0	24.0
47	33 PRIMARY METALS	185.3	8	11	80	.5	6	(-)5.5▲
6	ALL OTHER INDUSTRIES	26.7	31	18	3	6	15	27
100%	TOTAL MANUFACTURING	397.6	21	10	51	.8	4.2	13

▲ DUE TO COKE PRODUCTION EXCEEDING COKE USAGE.

Source: U.S. Department of Energy

FIGURE VI-4

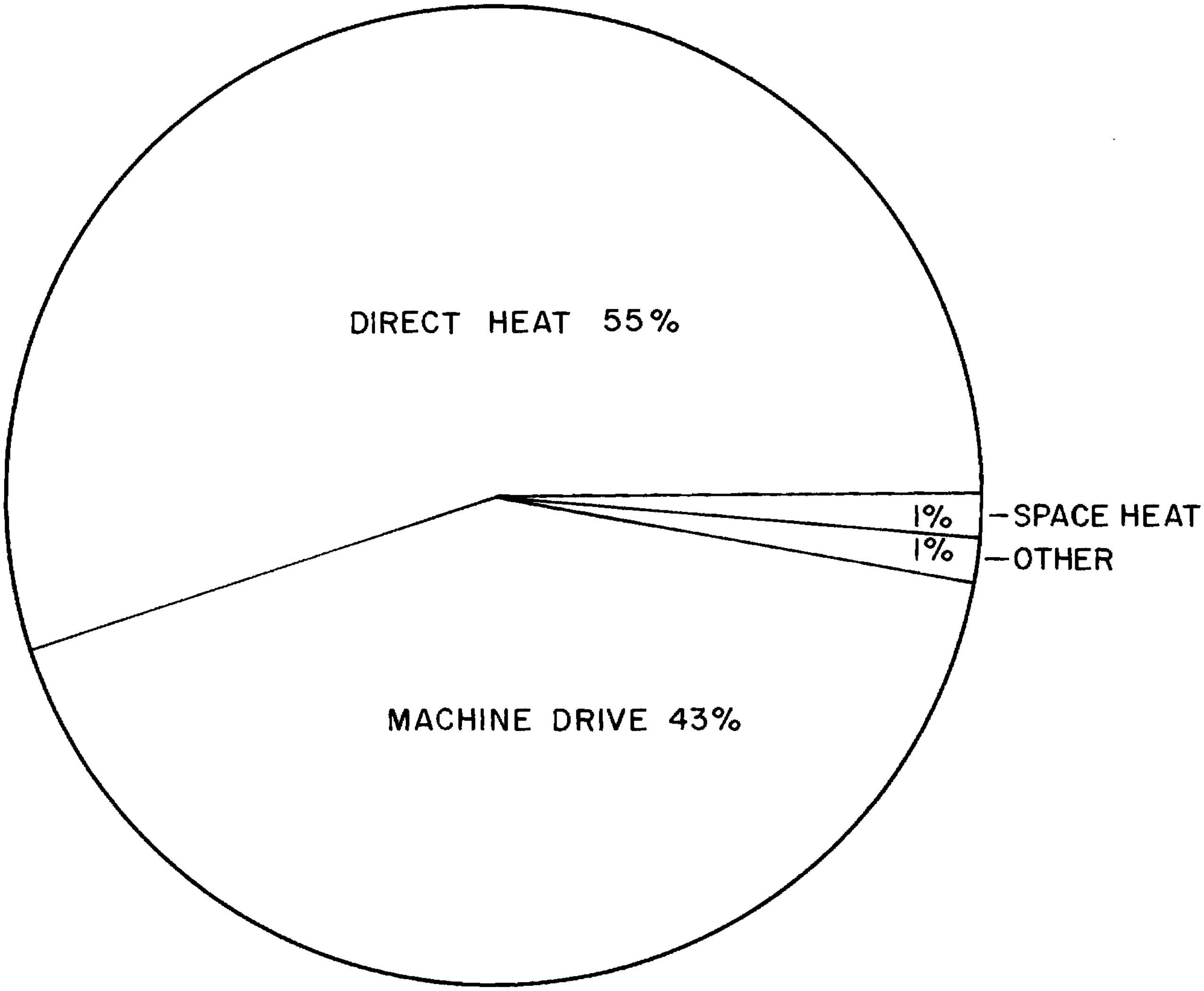
WEST VIRGINIA NET IMPORTS AND EXPORTS OF NATURAL GAS



Source: West Virginia Fuel and Energy Office

FIGURE VI-5

FUNCTIONAL USES OF ENERGY IN THE STONE, CLAY, AND GLASS INDUSTRY



Source: U.S. Department of Energy

input as wood gas is introduced. Where such output reductions can be tolerated, such as in cement kilns, wood retrofit has potential; where it cannot, new equipment properly sized for wood must be used. If firms in the Stone, Clay and Glass sector used wood to meet only one-third of their 1974 demand for natural gas, 3.5% of West Virginia's 1974 natural gas demand or nearly 14% of that year's natural gas imports would have been alleviated.

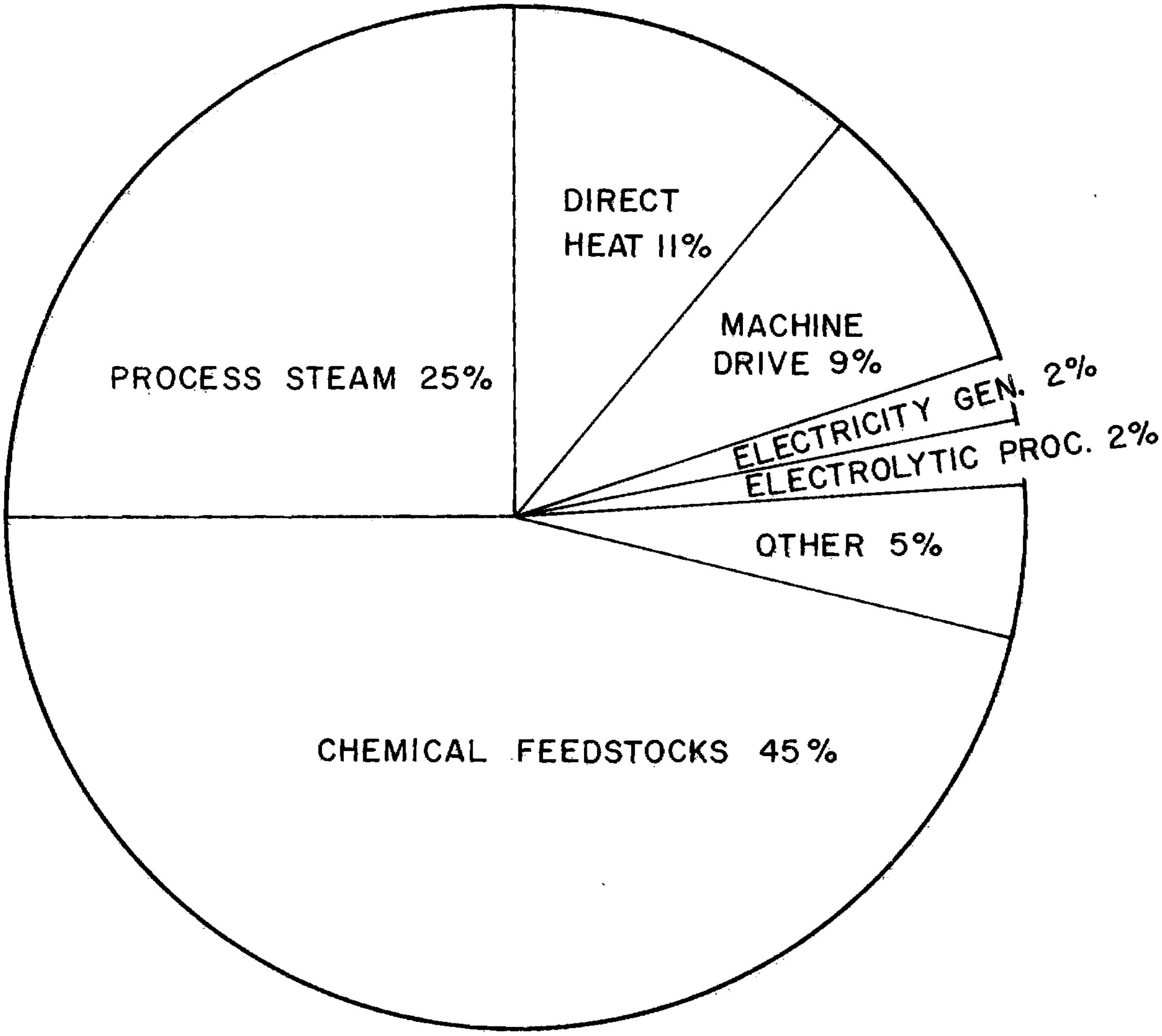
In the Chemicals industry, approximately 45% of the energy used in 1974 was as raw material feedstocks for conversion to chemicals. Outside of feedstock consumption, the majority of energy was used for process steam. Significant amounts also were consumed for direct heat, machine drive, electricity generation, and electrolytic processes. Space conditioning and lighting uses were not significant (see Figure VI-6).

Natural gas is used extensively in the Chemicals industry in West Virginia, making up 25% of its 1974 energy consumption. About 40% of this was used for feedstock purposes, with the rest for heat and power. While wood in the past has been a source of chemicals, its use as a chemical feedstock is not considered promising in the near future. Current chemical technology is geared for concentrated petroleum feedstocks, and additional research would be required to determine if wood economically can replace petroleum chemical feedstock.

However, the remaining natural gas used for direct heat drying, steam production, and machine drive can indeed be supplemented with wood. As mentioned earlier, wood gasification results in a product that can typically be used in natural gas equipment with little modification. If the Chemical sector had used wood to meet only one-third of its 1974 demand for natural gas as a non-feedstock, 3.5% of West Virgnia's 1974 natural gas demand or nearly 14% of that year's natural gas imports would have been alleviated.

FIGURE VI-6

FUNCTIONAL USES OF ENERGY IN THE CHEMICAL INDUSTRY



Source: U.S. Department of Energy

Finally, the Primary Metals industry in West Virginia is a coal-intensive industry. Fuel oil and natural gas, however, have been used to reduce coke requirements in blast furnaces. Figure VI-7 shows the breakdown of energy use consumption for the industry in 1974. Wood firing in blast furnaces needs further research due to the high quality fuel requirements for the ore reduction process. Charcoal is a possible fuel form, but is costly to produce in relation to wood chips. Reheat furnaces could use more conventional wood fuel, but it is doubtful there is a great demand for supplemental fuels in reheat furnaces since coke oven gases and waste heat are readily available. In general, the potential for wood usage in the Primary Metals industry appears very limited at this time.

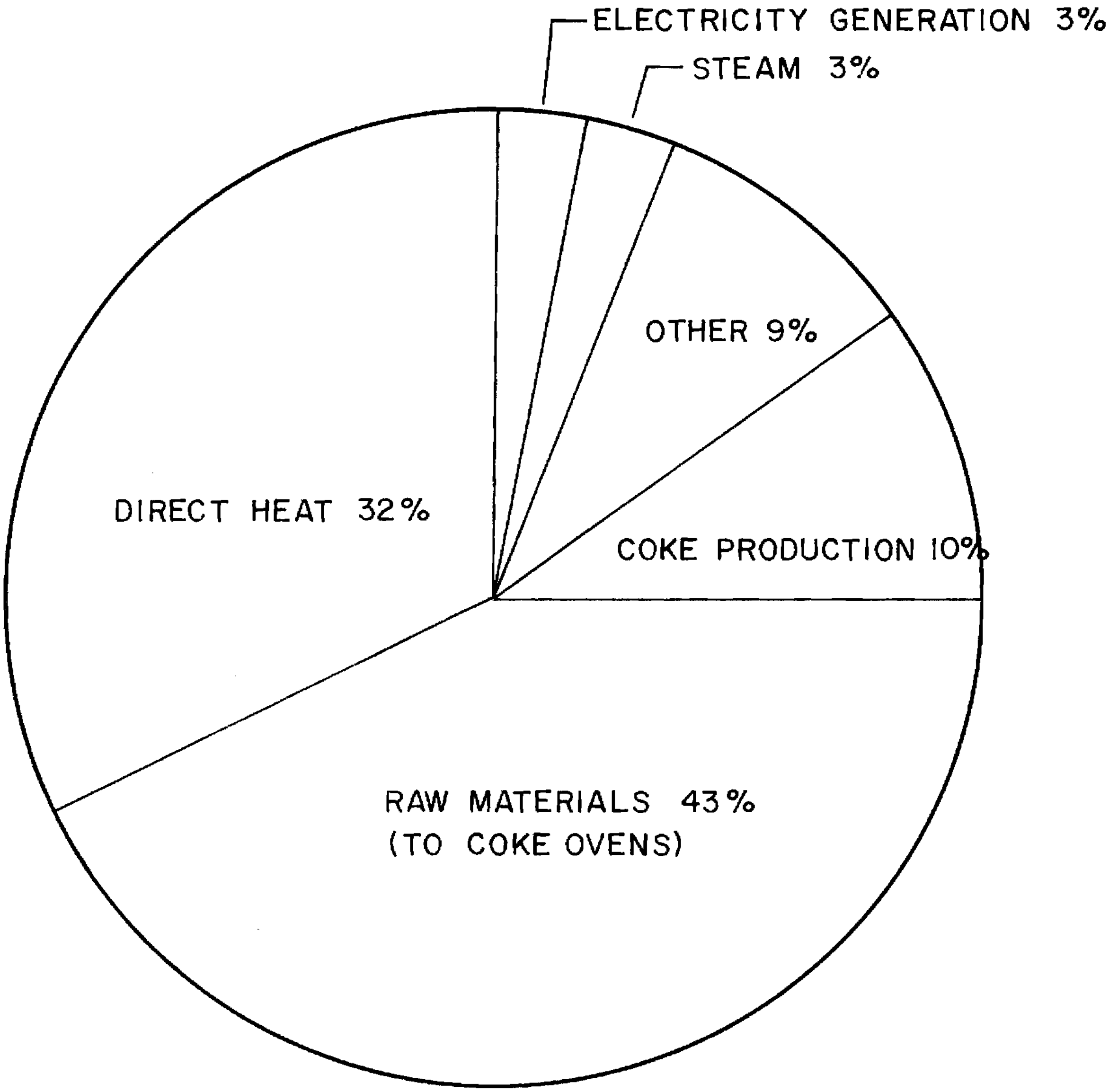
Tranportation Applications

Gasoline consumption represents perhaps the most publicized area of fuel consumption where imported fuel is used, not only in the state, but in the country as well. In 1974, passenger car gasoline usage in West Virginia represented 45% of all fuel used in the transportation sector, or nearly 5% of West Virginia's total fuel usage for that year.

Wood can be used to produce ethanol for use in gasohol. Research is currently under way to develop further ethanol conversion technology. Using current gasohol mixing formulas of 10-90 for conventional car engines, wood could provide 4.5% of West Virginia's transportation energy needs, based on 1974 consumption estimates. Further, gasohol could be protection against impacts on West Virginia's tourist industry brought about by gasoline shortages, since gasohol would increase the available supply of gasoline nationally. Finally, gasohol could provide an export market for ethanol produced in West Virginia.

FIGURE VI-7

FUNCTIONAL USES OF ENERGY IN THE IRON AND STEEL INDUSTRY



Source: U. S. Department of Energy

Wood as a Substitute Fuel in the Industrial Sector

In West Virginia, the industrial sector consumed 410 trillion Btu's of energy in 1977. Thirty percent of this consumption was met by coking coal and petroleum coke, 22% by coal (excluding coking coal), and 22% by natural gas. Of these three major fuel sources, wood can be expected to compete only with natural gas.

Natural gas has been escalating rapidly in price in recent years and should continue to increase with world oil prices. This can be related to several activities. First the Natural Gas Policy Act (NGPA) provides that interstate pipeline companies set aside a portion of the acquisition costs of gas supplies to be passed on to low priority industrial users in the form of a surcharge. This surcharge, although limited to a ceiling (assumed to be the Btu-equivalent wholesale price of distillate oil), would result in unfavorable pricing of natural gas to these industrial users.

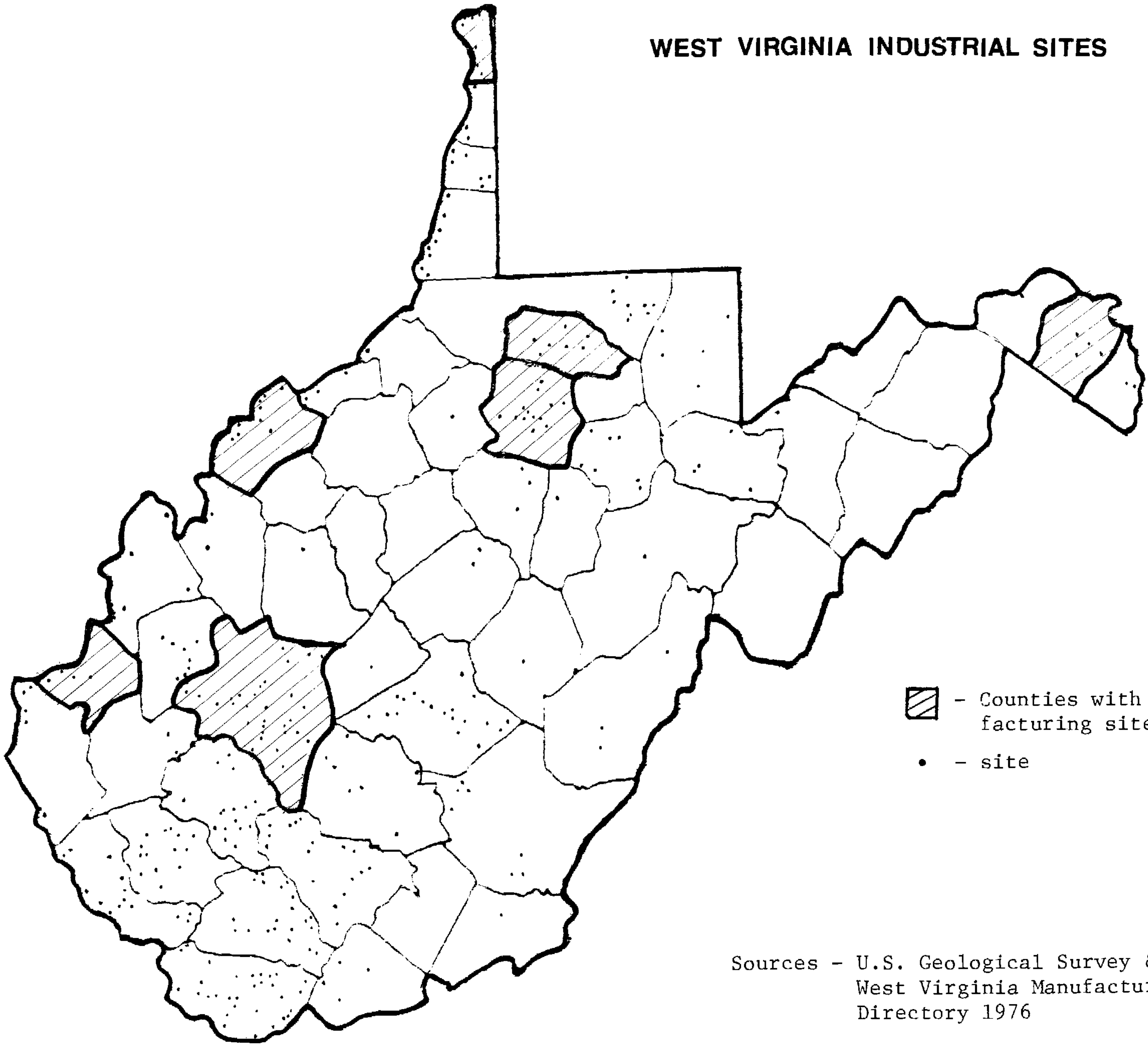
Further, the relaxation of interstate price controls under the NGPA should result in the development of additional gas markets. Depending on the makeup of this market (which should be residential and commercial) and seasonal demand variances, it can be expected that supplies will remain tight and keep prices high.

Wood, on the other hand, is not expected to compete with coal. Current costs for coal are substantially cheaper than wood (even high cost metallurgical coal) and with current demand at a lull, producers can be expected to keep price hikes at a minimum in an attempt to spur demand. Also, distribution and handling network costs have already been invested for coal giving it an even further advantage over wood.

Figure VI-8 shows the location of identifiable industrial sites in West Virginia as determined from satellite photographs. Major manufacturing sites are located in the shaded counties

FIGURE VI-8

WEST VIRGINIA INDUSTRIAL SITES



Sources - U.S. Geological Survey & the West Virginia Manufacturing Directory 1976 which compose portions of the Ohio, Kanawha, and Monongahela river valley concentrations of industry. The numerous sites in the remaining counties reflect the state's large primary resource extraction industries (coal, stone, etc.) located in the south and central portions of the state. From this figure it is evident that a portion of the wood will have to be transported from the densely wooded eastern and southern forests to the heavily industrialized manufacturing areas in the northern and western portions of the state. As with coal, the transportation medium will depend on cost, system availability, and network integrity. Until these networks are refined, the initial medium will also depend on flexibility.

Until manufacturing demand grows to a level compatible with available supply, resource extraction industries such as stone and coal producers should find uses for wood that must be cleared from surface extraction areas. These uses can be either in the form of heating remote field offices or providing mulch for reclaimed land.

Summary of Wood Energy Applications

Wood energy usage in West Virginia holds great promise. Clearly, wood has potential as a supplement for natural gas in both the Chemicals and the Stone, Clay and Glass sectors, thereby reducing the amount of imported natural gas to the state. If these two sectors alone consumed wood to supplement one-third of their natural gas demand for direct heat, process steam, and machinery drive, a little over 1% of the state's total energy need or as much as 15 trillion Btu's could be provided by wood. With natural gas prices currently at $3.00 per million Btu's and forecast to rise as high as $4.24 per million Btu's by 1995, wood energy substitution in West Virginia at $2.67 per million Btu's can be expected to be an economical one.

Wood usage in the Primary Metals industry needs further research. Unfortunately, demands for natural gas by this sector are in the blast furnace operation where special fuel requirements restrict simple combustion of wood. Charcoal is a form of wood fuel which could be acceptable for such use, but is questionable regarding its economics of substitution.

Ethanol production from wood also holds promise for blending with gasoline. While research is still being conducted in this area, West Virginia stands to benefit from it with possible ethanol sales both within and outside the state. Instrastate ethanol usage alone could supplement as much as ½% of the state's total energy need or as much as 6 trillion Btu's.

Wood mixing with coal is an area where further research should be conducted. Clearly, wood can reduce the sulfur content and fly ash removal problems of certain West Virginia coal. Whether suitable mixtures would substantially improve the sale of this coal depends both on the attractiveness of the wood/coal mix as a boiler fuel stock and the availability of wood supplies. On a 1:1 energy ratio blend, the state's entire renewable wood energy supply (67 trillion Btu's) could provide a blend equivalent to only 6% of West Virginia's 1977 coal production.

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VII. IMPACTS OF EXPANDED WOOD ENERGY USE IN WEST VIRGINIA

Part A. Environmental Impacts

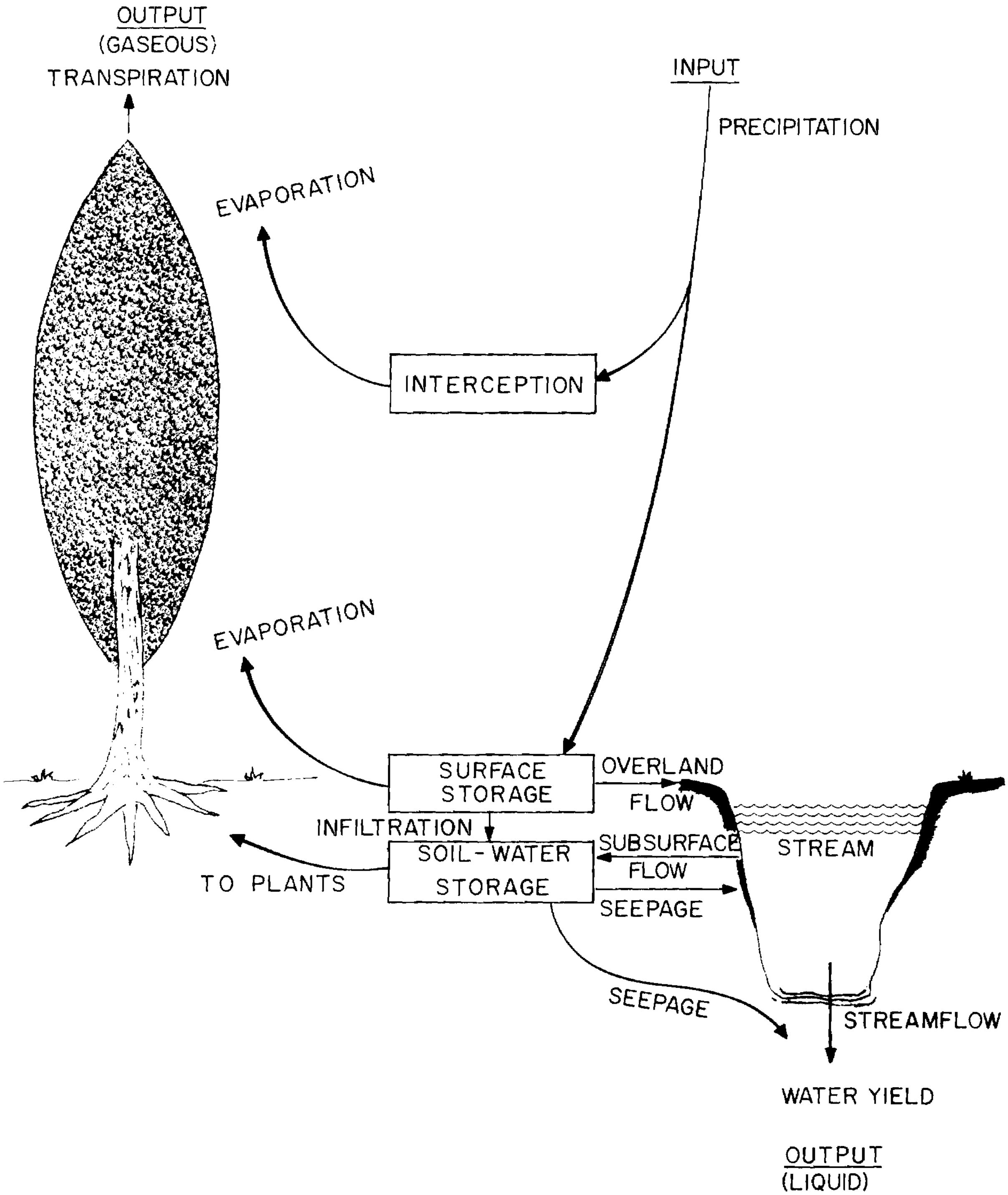
The expanded use of West Virginia's wood resources will not harm the environment if proper care is taken in harvesting the wood and in converting the wood to energy. The Fernow Experimental Forest in West Virginia is a nationally known center for forest research whose staff continually investigates the impacts of harvesting on the entire forest ecosystem. Forests are managed for a variety of objectives -- wildlife, recreation, timber harvest, wilderness, grazing, and watershed. Fernow, along with other research centers across the country, has done much to quantify environmental impacts and to provide improved procedures for multipurpose forest management.

The major concern in converting the harvested wood to useful energy involves air quality. Combustion of wood often generates smoke containing particulates and lesser pollutants that are spewed out into the atmosphere. Within the last decade, the public has become more conscious about the quality of the air we breathe. As a result, the Clean Air Act and subsequent amendments governing air pollution emissions were passed into law. Some conversion technologies can meet these standards. Those that cannot will require pollution control equipment. Most of this equipment, however, is available as off-the-shelf current technology items.

Watershed and Water Quality Impacts of Harvesting Fuelwood

Timber harvesting affects the water resource by its influence on the hydrologic cycle. In order to understand these effects, it is first necessary to understand the cycle (Figure VII-1). Water is introduced as precipitation. Part of it is intercepted by the leaves and branches of the tree, where it is either absorbed or evaporated to the atmosphere. The rest falls on the forest floor, where it is temporarily

FIGURE VII-1
THE HYDROLOGIC PROCESS



stored in the litter or soil surface depressions. From there, the water that does not evaporate either flows overland or infiltrates the soil. Underground, a portion is drawn into the tree by its roots and eventually transpires through the leaves. The remainder interacts with the stream underground, depending on whether it is stored above or below the water table. Water yield, or output, is measured as streamflow plus seepage from groundwater storage and is that part of the precipitation not used on the watershed.

A forest's influence on the water resource depends on type, age, and density of the stand, as well as topography, soils, and climate of the area. The extent of the influence depends on the intensity of the changes and the proportion of the watershed affected. For example, if 1% of a 100,000-acre forest is cut in a solid block of 1,000 acres, there will be a substantial increase in local streamflow. On the other hand, if 10 blocks of 100 acres each are dispersed over the entire forest area, the impact on flow of individual streams is reduced considerably.

Interception. Harvesting trees reduces interception, thereby increasing the amount of moisture reaching the forest floor. In conventional hardwood harvesting, tops and limbs as well as understory vegetation are left in the forest. These intercept almost as much moisture as standing trees. Harvesting energy wood where all timber is cut and removed from the site, therefore, would have a greater impact on the water cycle.

Surface Storage. Most studies of surface storage have been concerned with snow accumulation. Snow under the forest canopy melts later in the season than snow in cut areas. The result is a desynchronization of peak flow by spreading the snowmelt over a longer period of time. Soil surface depressions due to logging operations would increase surface storage somewhat; however, these effects have not been evaluated separately.

Infiltration. Water infiltrates rapidly when deep and permeable soil lies beneath the litter layer. Rates of 50 inches per hour or more are common in undisturbed moist climate forests (greater than 30 inches mean annual precipitation), far greater than extreme rainfall intensities of two inches or less. Cutting trees, therefore, does not affect infiltration capacities. However, careless logging operations can disrupt the protective surface cover, exposing and compacting the mineral soil and reducing infiltration significantly.

Erosion. The geologic norm for undisturbed forests is somewhere between 0.05 and 0.3 tons of soil per acre per year. Most of this loss occurs at the stream bank where no protective layer of organic matter exists. The road construction and timber dragging associated with harvesting can increase these amounts considerably. Erosion measurements from logging roads in the Appalachians have ranged from 0.5 to 17.0 cubic feet of soil per foot of road. Skid trail erosion has no relation to harvest method. In fact, selective cutting may be more severe because roads are used more frequently. Tractor logging is generally more disruptive than cable logging. The key to lessening the environmental impact of logging is careful planning. At the Fernow Experimental Forest, sediment production was cut nearly in half when proper slope and drainage provisions were made. Numerous publications are available describing acceptable engineering practices for the construction of logging roads. When these methods are applied, forest watersheds can be logged without serious degradation of water quality.

Soil-Water Storage. Capacity to store water can be slightly reduced by cutting trees because accumulations of humus are reduced. Opportunity to store water may be greatly reduced during the growing season and for some time afterward. Duration of the effect of tree cutting is related to soil depth. Seven years after commercial clearcutting of a shallow-soil watershed at the Fernow Experimental Forest, 78% of the original increase in streamflow had disappeared. On a watershed at Coweeta Hydrologic Laboratory with a much deeper soil, 20 years were required to achieve a similar reduction.

Streamflow. Cutting trees increases streamflow; the heavier the cut, the greater the increase. The duration of this increase, however, is variable, depending on magnitude of the initial increase, the type and intensity of the cut, and the rate of regrowth. At Fernow, a first-year increase of 5.1 inches was reduced to 0.5 inches after 10 years. On a selection cut, an initial 2.5-inch increase was reduced to a negligible amount in three years. Selection cuttings and thinnings have only transient influences on water yield because cut spaces are rapidly overgrown. Clearcutting causes maximum first-year increases up to 18 inches. Streamflow always decreases as the forest regrows. Flow differences are negligible as long as cut areas are a small proportion of the entire forest.

Seasonal timing will make a difference in streamflow. However, studies in Japan, West Virginia, and South Carolina indicate that timber can be cut heavily without causing watershed deterioration that results in overland flow, although some peak flows increase. Destruction of eastern forests at the turn of the century followed by wildfire, overgrazing, and steepland agriculture did increase flooding. However, most present day hydrologists agree that intelligent harvesting cannot increase the severity or frequency of flooding.

Water Quality. Turbidity is increased by erosion of logging roads. Logging roads that drain directly into small forest streams have resulted in measured turbidities of 3,500 ppm to 56,000 ppm. (The threshold level for damage to fish is about 400 ppm.) Measurements on carefully logged watersheds, as a comparison, ranged from 210 ppm down to 25 ppm. As mentioned before, proper construction techniques are absolutely essential to keep erosion to acceptable levels.

Fertilizer pollution of forest streams is presently not a major problem because few West Virginia loggers use it to develop dense stands of grass as road stabilizers. However, the risk of pollution by fertilizer would be preferable to major pollution by eroded soil.

Temperature of streams can increase when trees are harvested along stream banks. At Coweeta, the temperature of an open farm stream dropped from 80°F to 68°F after passing through 400 feet of forested channel. Stream temperatures at Fernow were raised as much as 8°F after cutting along the banks. Without the shade of a forest canopy, cold water streams can become warm water streams, lower in oxygen and less desirable for trout. Although some arguments are valid for increasing temperatures of very cold streams, leaving a band of trees wide enough to keep streams shaded probably will have the least impact on the ecosystem.

Water chemistry is affected only slightly by harvesting. The only study that has shown drastic increases in dissolved nitrate levels was at Hubbard Brook in New Hampshire where all timber was cut and all regrowth prevented by repeated treatments with herbicides: nitrate concentration increased from 1 ppm to 58 ppm. In West Virginia, during two years after a clearcut operation, maximum nitrate concentration was measured at 1.4 ppm, too small to be of major consequence.

Other Impacts of Harvesting Fuelwood

Temperature and Climate. Tree removal exposes the cut area to more direct solar radiation, resulting in greater temperature extremes. Frost pockets may form in cold weather; surface temperatures may rise high enough in warm weather to inhibit regeneration. Care should be taken in harvesting wood for energy that removal of slash ordinarily left behind will not also remove the artificial shade normally provided for the seedlings. On the other hand, hardwood species are vigorous sprouters, and growth may be enhanced by high temperatures.

Ground-level wind patterns are altered depending on the size of area cut. Wind turbulence increases at the boundary of the cut area, exposing trees left behind to higher wind stresses. There would be, however, little climatic impact beyond the logged area.

Soils. Without the shading effect of the forest canopy, surface soils warm up more rapidly. This in turn causes more rapid decay of the organic layer, making nutrients more available to new plants. Moisture of the soil is also increased because removal of trees not only eliminates transpiration, but also allows more precipitation to reach the ground. Poorly drained soils may become too wet for regeneration, but growing conditions are improved on medium to dry sites.

The consensus of opinion on nutrient balance in soils after harvesting is that nutrient levels will not be depleted, even after clearcutting. There is, however, some concern that short-rotation plantations (the growing of trees as a crop) may adversely affect soil fertility. Studies are continuing at this time.

Site. Initial quality of the site will determine the effects of logging operations. Regrowth is slower on poor sites and additional stress, such as drought, fire, or heavy browsing by deer, can cause understory shrubs to dominate. Position on the slope is also important. Ridgetop soils are shallow, low in nutrients, and deficient in waterholding capacity. Farther down the slopes, soils are generally of better quality. Intense solar radiation makes slopes facing south and west more susceptible to longer lasting effects.

Forest Types. Sixty percent of West Virginia forestland is covered by oak-hickory stands. Early cuttings in these forests removed only the high quality oaks, black walnut, yellow poplar, and black cherry. Low quality inferior species were thus left to take over the forests.

Most research in the past 30 years has shown that even-aged management will yield maximum production of high quality timber with rotations of 60 to 75 years for veneer and sawtimber. A clearcut for energy wood will stimulate advanced reproduction through sprouting. Improvement cuttings are sometimes justified prior to final harvest and also can yield energy wood.

Selection or shelterwood cuttings do not work as well as clearcutting because trees just outside the cut area border develop branches in the otherwise clear, unknotted portion of the stem, lowering log quality.

Most people find a mature stand of timber aesthetically pleasing. The loss of such a stand, together with the appearance of devastation after a cut, is strongly objectionable. This is especially important in oak-hickory forests close to population centers and recreation spots. Because oak-hickory forests are regenerated so easily, either silviculture method will work. For top quality and most desirable stand composition, clearcutting is best; for recreation and aesthetic purposes, selection cutting is preferred. The shelterwood method would be a good compromise between the two.

Maple-beech-birch stands comprise nearly 2.8 million acres of West Virginia's forestlands. Most species are tolerant, so this type aggressively recaptures a site after logging. Dispersed recreation may be enhanced with judicious limited clearcutting, providing contrasts in forest cover and scenery for the hiker and casual forest viewer. Selection cuttings can be applied near concentrated recreation areas if cutting is considered necessary. Northeastern foresters advocate clearcutting for maximum timber benefits because of the serious logging damage suffered by the residual stand during partial cutting operations.

In summary, the northern hardwoods are the most versatile of forest components. Even-aged management is best, although selection cutting can be applied if species transition and operating economics permit.

West Virginia has 815,000 acres of the elm-ash-cottonwood forest type with red maple as a major component. These are found along major rivers and streams on soils with a high water table or poor internal drainage. Water yields are markedly increased after cutting. Cottonwood is highly intolerant and, in the absence of cutting or natural catastrophe, is quickly eliminated by the more tolerant elms and maples. The shelterwood and selection methods are not good alternatives to clearcutting in this type of forest stand.

Elm-ash-cottonwood stands are generally managed under an even-aged regime with clearcutting applied at maturity, followed by a program to control undesirable species such as box elder and privet. Cottonwood is difficult to establish from seed, so it is often regenerated by planting cuttings. Thinning promotes growth of the best trees.

Wildlife. Timing, size, and location of harvests are critically important to all species of wildlife. With proper planning, winter food supplies and prime habitat acreage can be increased. To be favorable to wildlife, cut areas must not be too large. Most species benefit primarily from the extra edges produced where forest meets open land. Cutting in small patches increases the amount of edge while stimulating growth of desirable food and cover plants. By producing a greater variety of plant species, it also improves the ecological stability in some areas.

For 10 to 20 years after cutting, deer populations increase noticeably. Ruffed grouse and snowshoe hare also benefit from clearings. Between 20 and 50 years after the cut, conditions in the cut area are poor for wildlife. Both forage and cover are sparse as a result of the dense overstory. But as long as cut areas are rotated, there will always be areas suitable for wildlife. From age 50 to the end of the rotation, mast and fruits are produced in quantity. As deer, bear, wild turkeys, grouse, and gray squirrels use the fruits, the area is once again inviting to wildlife.

Some wildlife lack environmental adaptability and high mobility; where they remain they should be afforded special protective consideration in any forest management plan.

Recreation and Aesthetics. Because the northeastern forests are close to many urban centers, they are subject to heavy recreational demands. Even-aged management cannot be considered bewteen ski trails or around picnic and camping areas unless thoroughly screened by trees. A cut area within walking distance might actually enhance the value of the area. It would offer visitors a chance to see plants and animals not found in the uncut forest. Variety would be added to hiking trails if they passed with explanations near areas where improvement practices were being conducted. Although vistas may be created and beauty may be present on a small scale within a cut area, both are short-lived, as regrowth takes place rapidly.

Air Quality Impacts of Wood as a Fuel

Wood smoke has caused air pollution problems from the time wood was first used as a fuel. Early campfires, locomotives, and uncontrolled industrial sources contributed smoke to the air. For many years, sawmill operators used "tepee" burners to dispose of sawdust, edgings, and other wood residues. This waste was burned under poorly controlled conditions, and heavy smoke often created problems for the sawmill's neighbors. These burners largely have been shut down today, and the unwanted by-products often are converted into useful energy. West Virginia regulations currently prohibit open burning of refuse.

At the large end of the woodburning equipment spectrum are the bark boilers and combination bark-fossil fuel boilers used by some utilities and most pulp and paper mills. These boilers, producing up to 500,000 lb/hr of steam, constitute large potential sources of pollutants in the eyes of enforcement agencies. Air pollution abatement devices that were developed for these boilers were not always effective. Only in the 1970's have major polluting sources been effectively cleaned up.

Air Quality Standards. The main concern in the burning of wood is the emission of particulate matter resulting from the combustion process. The presence of smoke indicates the presence of particulate, but the relationship between smoke and particulates is not always easy to analyze. Smoke results primarily from a combination of inorganic materials in wood that will not burn and particles of carbon and other combustible matter that have not burned completely. A dark plume from an industrial stack can indicate poor maintenance and poor operational practice, but it can also indicate an unavoidable situation such as a rapid load change or boiler upset.

Wood furnaces also emit carbon monoxide, oxides of nitrogen, and small amounts of sulfur oxides and hydrocarbons. The data base for these pollutants is not nearly as extensive for wood as it is for fossil fuel fired boilers. The EPA has published the emission factors shown in Table VII-1. These numbers are controversial, and many people in industry and the regulatory agencies themselves consider the numbers to be pessimistic.

Particulates. The calculation of emission rates of particulates for woodburning sources can be a complicated task. Historically, emission data have been reported as a mass loading concentration in grains per standard cubic foot. (A grain is 1/7,000 of a pound.) This number gives an indication of the total weight of particulate being emitted to the atmosphere. Testing requires collecting a representative sample of the particulate matter from the stack with a probe and estimating the volume flow rate of the flue gas. A lower concentration would, of course, indicate that the source was emitting less of a given pollutant. The shortcoming of this method is that no consideration is given to dilution of the flue gas. Boiler operators have been known to "turn up the fans" during tests to make the emission rate appear lower than it actually was.

Table VII-1

EMISSION FACTORS FOR WOOD AND BARK COMBUSTION IN BOILERS WITH NO REINJECTION

Pollutant	Emissions lb/ton of fuel
Particulates	25 to 30
Sulfur Oxides	0 to 3
Carbon Monoxide	2
Hydrocarbons	2
Nitrogen Oxides	10

This problem can be overcome by applying a simple correction. Data are adjusted to a given carbon dioxide (CO_2) level to account for the dilution effects of boiler leaks or variations in operating conditions. Concentration numbers are then reported as being "corrected to 12% CO_2." For wood-fired boilers, this percentage of CO_2 corresponds to an excess air setting of 68%, reasonable for normal operation.

Typical emission regulations limit the maximum particulate emission to so many grains per standard cubic foot of gas. To provide meaningful data, the "standard cubic foot" also must be corrected for variations in temperature, pressure, and flue gas water concentration at the test site. When these corrections are made, what originally appeared to be a low emission rate can increase several times.

In recent years, another method of reporting particulate emissions has become accepted. Data are reported as a mass emission per unit of energy input -- pounds per million Btu (lb/mm Btu) or nanograms per joule. Applying these units to a wood-fired source causes problems in measuring energy input. When a utility boiler is being tested, the flow rate of oil or gas to the burners is easily determined using flow-meters. Coal flow rate is also quite easy to determine using a coal scale. However, measurement of wood energy flow has not gained widespread acceptance. A weighing conveyor belt can be used but is not often found in the typical wood-burning boiler plant. This fact has created a problem for many regulatory agencies. If a regulation is written as "pounds per million Btu" or "pounds allowed for a given process weight," the operator of the source can report erroneous numbers for the amount of fuel being burned. If the operator suspects his source may be out of compliance with regulations, he can claim a much larger amount of wood is being burned than is actually the case. This will give him an allowable pounds per hour emission that is much greater than the emission he should be allowed. Measuring wood fuel continues to remain a problem for regulatory agencies, particularly since wood weight varies considerably with species and moisture content.

Methods of sampling for particulate matter vary from state to state. West Virginia recognizes TP2, a method requiring that samples be extracted isokinetically with the probe and filter media maintained at stack temperatures.

When a regulatory agency requires a compliance test to determine if a given source is operating within air pollution regulations, a series of tests are witnessed by a member of the regulatory agency. These tests are often run by a stack sampling team from a consulting or testing firm specializing in this type of work. Large companies may have such teams as permanent employees.

West Virginia particulate emission standards are shown in Table VII-2 for hand or stoker-fired units. Allowable emissions in pounds per hour for electric utilities are .05 times the total design heat input in million Btu's per hour, up to a maximum of 1,200 pounds per hour. Allowable emissions for all other fuel-burning units are .09 times the total design heat input, up to a maximum of 600 pounds per hour. State regulations exempt units with heat input under 10 million Btu's per hour. However, they state, "Failure to attain acceptable air quality in parts of some urban areas may require the mandatory controls of these sources at a later date."

Plume Opacity. The other emission measured by control agencies is "plume opacity." This variable is easily identified by the amount of smoke being produced. "Percent plume opacity" refers to the amount of reflected background light blocked by the source plume. An opacity of 100% will theoretically allow no light to pass through, while the background will be slightly obscured by a plume with an opacity of 20%. This emission measurement is probably more controversial than any other: it depends on the subjective opinion of a certified observer who has attended a smoke school run by a regulatory agency. The observer is taught where to stand with respect to the source and the sun when taking a reading and must verify his proficiency by observing repeatable plumes of both white and black smoke. Certification usually lasts six months to a year. Staff members of companies that have emission sources are urged to attend smoke schools so they can dispute reported violations that they consider unfair.

West Virginia regulations on plume opacity prevent the emission of smoke that is darker in shade or appearance than

Table VII-2

PARTICULATE EMISSION STANDARDS FOR HAND-FIRED OR STOKER-FIRED FUEL BURNING UNITS IN WEST VIRGINIA

Design Heat Input (million Btu/hr)	Allowable Emission Rate (lb/hr)
10	3.4
20	5.6
40	9.0
60	11.7
80	14.4
100	16.6
200	26.4
400	42.2
600	54.0
3,333	300.0

0.5 Ringlemann or 10% opacity under normal operating conditions. Slightly higher opacities with time limitations are allowed for start-up and clean-out. Again, units with heat input of less than 10 million Btu's per hour are exempt.

New Source Review. For proposed facilities or additions that will emit air pollutants, a New Source Review Application must be filed. Site location will determine what regulations will have to be met. Attainment areas are those locations that meet the National Ambient Air Quality Standard (NAAQS). Most of the state is considered attainment for particulates. Non-attainment areas for particulates in West Virginia are:

PRIMARY -- Hancock, Brooke, Ohio, and Marshall counties

SECONDARY -- Kanawha County and parts of Fayette, Wood, and Marion counties

The rules for the prevention of significant deterioration (PSD) of air quality are applicable to new pollution sources built in attainment areas, and they have been controversial in many instances. PSD review involves determining the available differential between ambient pollutant concentrates and ambient standards. The regulatory agency then determines what portion will be used up by the proposed new source. This process can result in stack emission limitations much stricter than those given in the regulations. Terrain and meteorological effects also can play a large part in emission limitations. If ambient air quality is not known, up to one year of ambient monitoring at the applicant's expense may be required.

It should be noted that EPA has proposed a number of changes to its PSD regulations based on a preliminary decision by the Court of Appeals in Alabama Power Co. vs. Costle. Related changes to emission offsets have also been proposed. Final rules will not be promulgated until 1980.

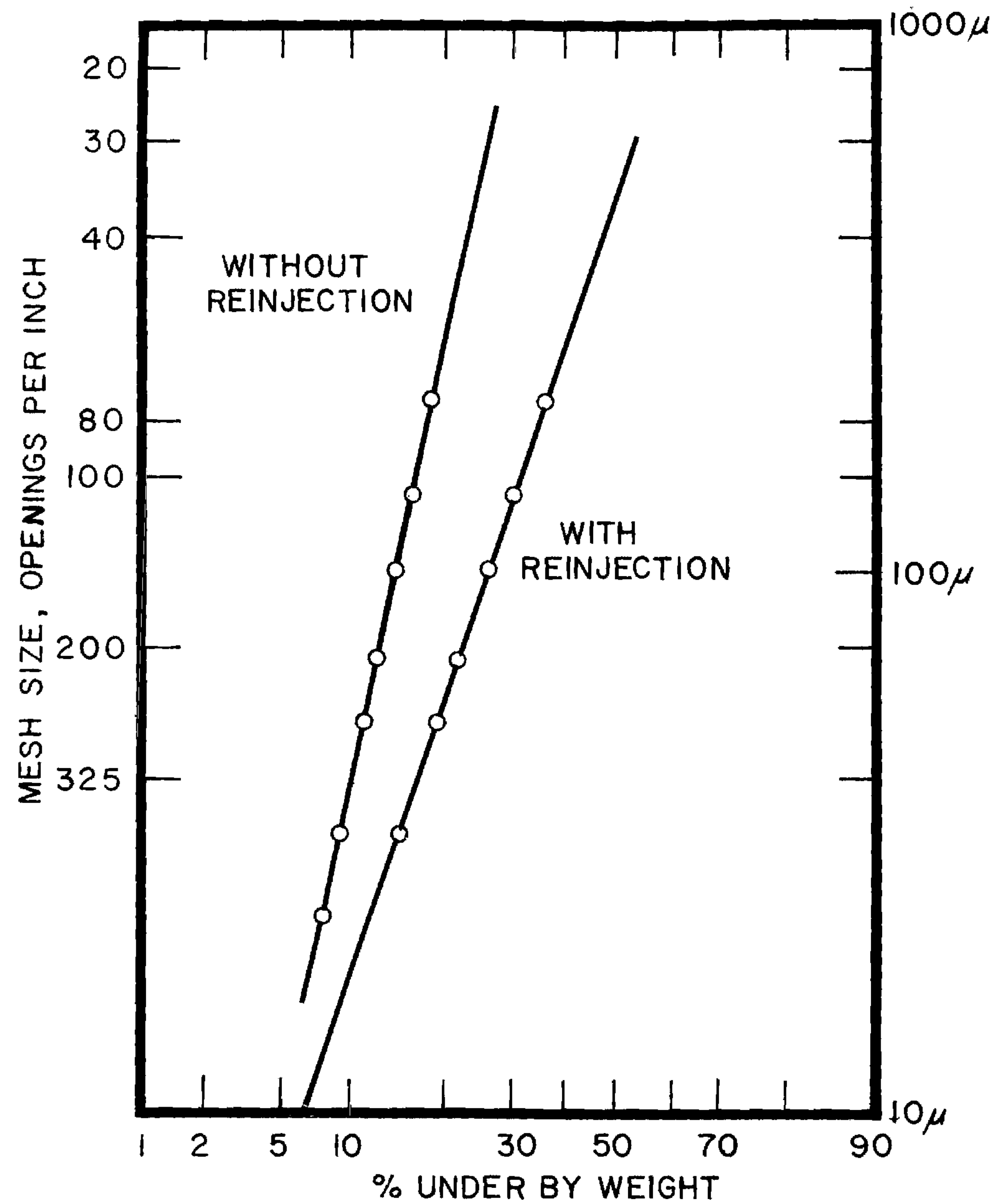
New sources can be built in non-attainment areas only if certain offsets are made. A company must ensure that the air will be cleaner _after_ emissions from the proposed new source are added. This can be accomplished by shutting down a company's own sources, by purchasing control equipment for a neighbor's sources, or by purchasing a neighbor's plant and closing it down. Lowest Achievable Emission Rate (LAER) control technology is required on new sources in non-attainment areas. LAER is more stringent than BACT because it represents innovative technology without regard to cost or energy use. Fabric filters and baghouses are considered by EPA as LAER technology for wood-fired boilers. New sources also must meet new source performance standards under federal regulations. Standards for woodburning installations are being considered but have not been promulgated. Each case considered under the new source review procedure is studied individually. Those considering a new wood-fired energy source should consult local, state, and federal pollution agencies early in the planning stages.

Source Characterization. There are a great many wood-firing systems on the market today. While each has the potential for being an air polluter, some are more prone to producing air pollution episodes than others. Particle sizes are of special interest for wood-fired sources, and some pollution control agencies are now specifying that the maximum size that can be emitted is 250 microns, a size that can result in considerable fallout problems local to the plant. In addition, regulations are being considered on the amount of small particles (less than 10 microns) that apparently are more dangerous to human health. Figure VII-2 gives a typical size distribution for wood-fired boiler particulates.

Conventional bed burning or spreader stoker burning results in particulate matter that may contain sand and dirt collected during harvesting, unburned carbon, and fly ash.

FIGURE VII-2

SIZING OF WOOD PARTICULATES



Cyclone burners, when operated properly and with the proper fuel moisture content, can have very low particulate emissions. Much of the fly ash and other uncombusted matter remains within the burner and can be removed periodically. Cases where cyclone burners create excessive emissions usually involve inadequate fuel preparation (wrong particle sizing for the system) and excessive fuel moisture content (over 15%).

Gasifier emissions are expected to be low, but at the present time there is a lack of published data on emissions by these systems. Most natural gas-fired boilers have little or no pollution control equipment since the combustion process results in little or no particulate emission. Oil-fired boilers create larger particulate emissions due to ash and other foreign matter in the oil, or incomplete fuel combustion due to poor burner maintenance or burner design. Again, however, a boiler designed to burn oil or a combination of oil and gas will generally have no flue gas cleaning equipment. Since one of the larger potential markets for wood gasifiers is the retrofit of close-coupled gasifiers to oil/gas boilers, the conversion will have to comply with existing emissions regulations for oil/gas boilers. This should be within the capabilities of the gasifier system if the problems of dealing with tars and other difficult-to-handle constituents of the wood gas are addressed. It should be noted that the retrofit of a gasifier to an existing boiler may be considered a modification to an existing source rather than the construction of a new source, thereby avoiding the more stringent New Source Performance Standards.

Fluidized bed and wet cell emissions in most cases will be similar to the emissions from conventional wood boilers. It thus will be necessary to incorporate some form of emission control.

Effects of Fuel Preparation and Operations. The emissions of a wood-fired combustion system can vary substantially according to how the system is operated and to what degree the fuel is prepared. This will be true of all systems, including conventional boilers, cyclone combusters, and wood gasifiers. Fluidized beds are probably less sensitive to fuel preparation than the other categories.

Fuel Preparation. Different species of wood have different characteristics with regard to chemical makeup, heating value, and density. It is important for the combustion system operator to know what is being burned, since minor control variations can significantly affect the emissions of wood-fired sources when fuels are changed.

Moisture content is, of course, the most important variable since it will be nearly impossible to maintain any fire on wood above 65% moisture content (wet basis). In most conventional boiler designs, the firing of some auxiliary fossil fuel will be necessary to maintain load when such high moisture fuel is being burned. The higher the moisture content, the more difficult it is to completely burn a particle of wood: a large portion of the existing fire's heat must be devoted to evaporating the water in the fuel. Moisture content also will be an important factor in wood gasifier operation since it may be difficult to obtain the desired quality gas and the desired drying effects on the input fuel.

For conventional boilers and cyclone wood burners, the importance of fuel sizing cannot be overemphasized. Spreader stokers require adequate hogging to produce a relatively uniform chip size for adequate burning. Pieces that are oversized can jam conveyors and will tend to stratify inside a furnace. The combustion system constructor or manufacturer should have a well-defined fuel specification that is closely followed by the system operators.

Operation. In order to ensure continued compliance with air pollution regulations, combustion system operators need to be provided with adequate instrumentation for monitoring system performance. The degree of sophistication will depend partially on the size of the initial investment, since it can be quite expensive and also will require frequent maintenance.

The control of combustion air is essential to any conventional wood-burning process, affecting both system emissions and efficiency. Wood-burning boilers generally require more excess air than gas, oil, or coal boilers. Inadequate excess air can result in smoking conditions. Too much excess air can result in lowered unit efficiencies and increased real emissions, since the fuel particles are not given enough time to combust adequately and are blown out of the furnace prematurely. Combustion air temperature is also important in wood combustion systems, particularly when wet fuel is being burned. If possible, preheaters should be used with wood boilers to facilitate fuel drying and to improve overall unit efficiency. Proper excess air instrumentation can assist the operator of conventional wood boilers, gasifiers, fluidized bed combustors, and other wood-burning equipment.

Monitoring equipment for smoke density also helps the operator do his job. Television cameras indicate obvious smoking conditions that may result in air pollution violations, but their usefulness is limited to daylight hours. In-stack opacity meters are another type of smoke-monitoring equipment. This smoke density instrument is essentially a spotlight beamed through the stack towards a photocell lens. An alarm is tripped when opacity exceeds a predetermined set point.

Control of wood fuel flow is difficult. Television cameras relieve the operator from having to check conveyor transfer points. Conveyor belts that weigh the fuel are most useful, but expensive. A readout on conveyor speed or traveling grate speed also can give the operator valuable information.

System maintenance can be extremely important to continued compliance with air pollution standards. Furnace air supply valves and air registers must be kept in good order. Refractory walls must be maintained for proper furnace operation, and burners for auxiliary fossil fuel firing must be inspected often. Even the most carefully designed and sophisticated wood energy systems complete with air pollution controls cannot continue to operate in compliance with regulations if necessary maintenance is not performed. Requirements for periodic source testing imposed by pollution control agencies help to ensure that maintenance is performed.

Pollution Control Equipment. Wood-fired combustion devices represent potential sources of air pollution that are of great interest to regulatory agencies. But technologies are readily available as off-the-shelf items that can be used to cope with potential problems. Cyclones, scrubbers, electrostatic precipitators, and baghouses are described in Appendix G.

Part B. Economic Impact

Background

A number of different analytical approaches are available for estimating the impact on a given geographical region of an initial increase in expenditures. This economic impact is normally measured in terms of increased income and/or employment. Among these estimating techniques are economic base studies and input-output (I-O) analyses.

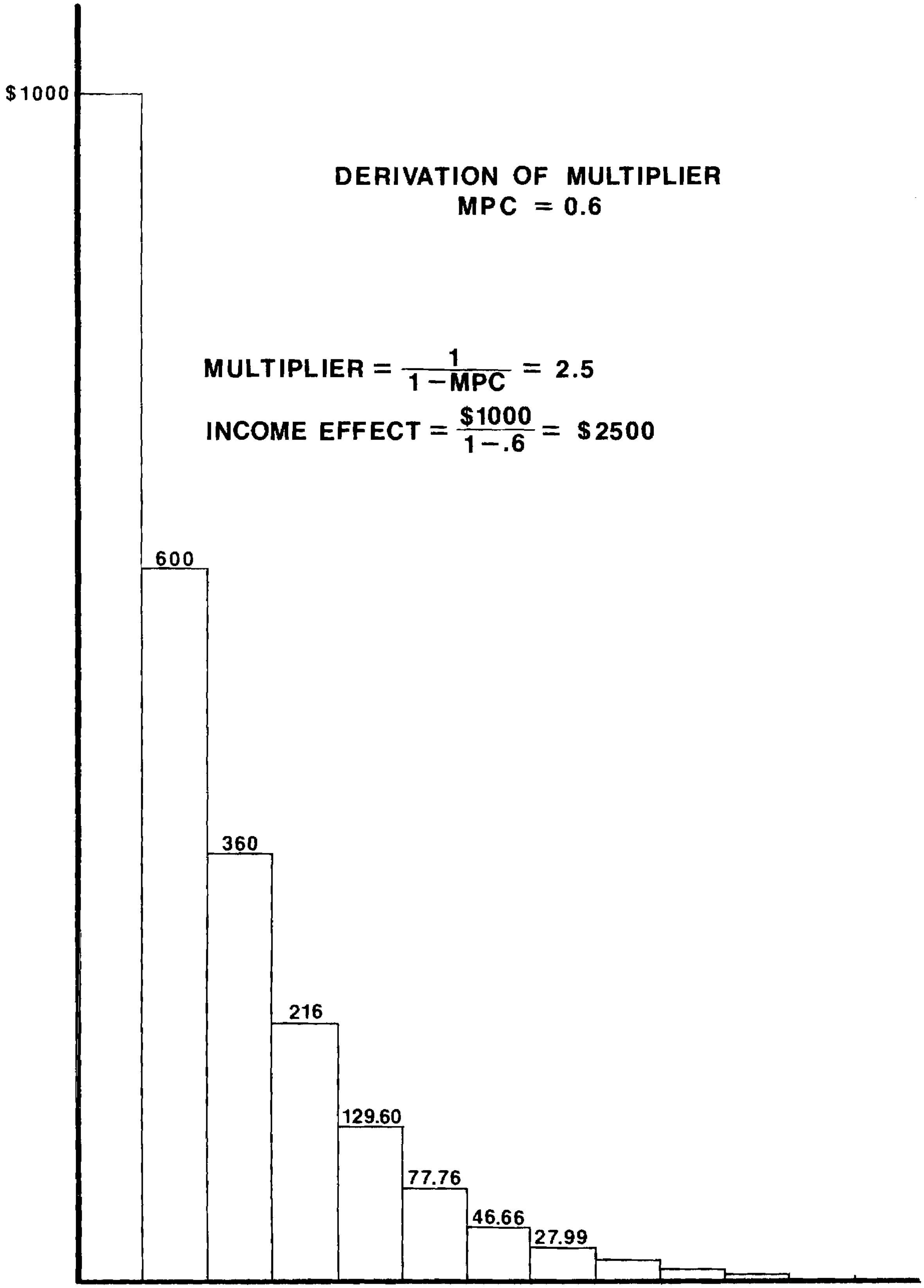
Multiplier Effect. Both of these methods inherently rely on and incorporate what is known as the "multiplier" effect. At its most basic level, economic multiplier theory holds that an increase in expenditures brings about an increase in income. This increase in income is greater, by some factor, than the additional expenditure. This factor is known as the multiplier. The original Keynesian income multiplier was developed in macroeconomic theory for application on the national level.

The multiplier is, in turn, based on the concept of marginal propensity to consume (MPC). The MPC is the amount of extra consumption, or spending, that is generated by an incremental increase in income. To illustrate both concepts, an MPC of 3/5 or 0.6 for a given economic sector means that for every $5 of additional income received, $3 is spent and $2 is saved. For a given expenditure of $1,000, for example, $600 would be spent, assuming the recipient(s) were characterized by an MPC of 0.6. This new round of spending, if restricted to the geographic area under consideration, represents additional income to that area, as did the first $1,000. So far, then, an initial expenditure of $1,000 has resulted in $1,600 of additional income.

This logic then repeats itself, with each new spending round becoming progressively smaller until the process damps down. Figure VII-3 illustrates the multiplier concept. For

Figure VII-3

THE MULTIPLIER CONCEPT



this specific example, a summation of all successive spending rounds (25 in all before becoming smaller than 0.5 cent) yields a total of $2,500. That is, an initial expenditure of $1,000 brought about a $2,500 increase in area income. The multiplier here, then, is 2.5.

For any given application, the multiplier can be calculated from the equation:

$$\text{Multiplier} = \frac{1}{1 - \text{MPC}}$$

This was derived from the formula for convergence of an infinite geometric series. That is, a geometric series of the form

$$a + ar + ar^2 + \ldots + ar^n + \ldots$$

converges if r is greater than minus one and less than plus one. When convergent,

$$\sum_{n=1}^{\infty} ar^{n-1} = \frac{a}{1-r}$$

Applying this mathematical theorem to the multiplier derivation, r becomes the MPC, and the initial expenditure is represented by a. Going back to the earlier example, the multiplier would be calculated as 1/(1-.6) or 2.5, and the total income effect would correspondingly be $1,000/(1-.6) or $2,500.

The original Keynesian multiplier mentioned earlier has direct analogies at the regional level in the form of regional income and economic base multipliers. The basic difference between the national and regional multipliers is the existence of interregional leakages through imports. These multipliers are similar in that they fail to distinguish between the industrial sectors in which the initial expenditure changes originate.

Economic Base Studies. Economic base studies are relatively simple and inexpensive; they produce a single multiplier for a given region, as mentioned above. These studies generally use employment as a substitute for income in a region due to the availability of employment data by small areas. Based on one of several methods, total employment for the region is divided into those producing goods for export from the region and those producing goods for local consumption. The usual underlying assumption of these studies is that employment is proportional to income, which allows calculation of the proportion of income spent locally (total employment generated by local consumption divided by total employment). The economic base multiplier may then be derived with the additional assumption that the marginal propensity to consume (MPC) equals the average propensity to consume; in other words, that the MPC does not change with level of income. This is not necessarily a valid assumption, however. In fact, studies have shown that the MPC for a region tends to increase as regional income increases.

Other inherent drawbacks to the economic base study relate back to the proxy use of employment rather than income. This approach ignores the fact that different occupations have different wage levels. An increase in the employment level of a high-wage industry would obviously have a greater impact on regional income than a similar increase in employment in a low-wage industry. Employment figures also neglect any change in productivity levels that might occur, which again would affect income.

In summary, then, the economic base study does have shortcomings and is generally considered unsuitable for long-range forecasting. However, it can prove to be a useful tool for rough approximations of short-term economic impacts on a given region.

Input-Output Analysis. The other technique mentioned earlier was input-output (I-O) analysis. An I-O model for an economic region characterizes the flows of goods and services between industries in that region. Each industry in the study region is presumed to require a specific set of inputs from other industries to produce its own output. The I-O model details these various interactions between industries in the form of a transactions table. Such a table typically presents the interaction data as a matrix, with columns and rows corresponding to the industrial sectors broken out for study.

Table VII-3 is an abbreviated, hypothetical I-O transactions table. The first column, for example, shows that the agriculture and mining industrial sector required a total of $100 million in input from other sectors to produce its own output. Twenty-five million dollars of the input is shown to come from the agriculture and mining sector itself for intermediate use. This could include grain as feed for livestock, for example. Another $10 million was spent to purchase goods from the food processing industry, $2 million for buying production from other manufacturing industries, and $4 million for the real estate and financial services of the region. These are only the inter-industry purchases; these inputs had to be combined with labor provided by households for final production of output. Fifty million dollars worth of labor was required for agriculture and mining's production of goods in this example. Row 8 shows that not all required inputs could be found within the hypothetical study region; $9 million worth of imports from outside the region was also needed.

The data presented in a regional I-O transactions table are classified as either primary or secondary, depending on their source. Regional I-O models derived from survey, or primary, data (i.e., personal interviews, mail or telephone surveys of manufacturers) are considered more accurate and useful than secondary models, which manipulate and convert published national statistics to estimate regional trade flows on a residual basis.

Input-output analysis is useful in projecting the economic impact on a region resulting from an increase in expenditures in a given industrial sector; that is, for an

Table VII-3

HYPOTHETICAL I-O TRANSACTIONS TABLE

Producing Sectors	Agriculture and mining (1)	Construction (2)	Food and kindred products (3)	Electrical machinery (4)	Other manufacturing industry (5)	Real estate and finance (6)
(1) Agriculture and mining	25	1	33	--	11	--
(2) Construction	--	--	--	--	--	--
(3) Food and kindred products	10	--	17	--	5	--
(4) Electrical machinery	--	2	--	4	11	--
(5) Other manufacturing industry	2	6	2	3	17	11
(6) Real estate and finance	4	1	1	1	6	1
(7) Households	50	14	26	45	40	36
(8) Imports	9	16	21	47	10	2
TOTALS	100	40	100	100	100	50

increase in demand for the production of that sector. The projection is accomplished through the use of multipliers generated from the data on inter-industry transactions. Both income and employment multipliers can be developed for this purpose.

As mentioned earlier, the main difference between the I-O income multipliers and the standard regional income and economic base multipliers is that the former are disaggregated for the various industrial sectors.

This recognizes the fact that the total impact on income (indicated by both output and employment) will vary according to which sectors undergo an expenditure change.

Two different types of I-O income multipliers have been widely used. Type I income multipliers take into account both the direct and indirect effects of a change in expenditures. As previously mentioned, increased demand for the output of an industry causes expenditures in that sector to increase. The direct effect is that the industry must increase its purchases from its supplier sectors. The indirect effect is that these supplier industries must, in turn, increase their purchases to support their increased output. The Type I multiplier encompasses the sum total of both these effects.

The Type II multiplier takes into account direct, indirect, <u>and</u> induced effects of a change in expenditures, and thereby gives a more complete measure of the ultimate regional economic impact of an increased expenditure. The induced effect refers to the induced consumption effects of expansion in final demand, or the repercussive effects of secondary rounds of consumer spending. That is, households would receive additional income due to their supplying additional labor to support the requirements for increased production. A certain portion of this additional income would be spent and add to the multiplier effect as explained earlier.

In summary, then, the formulae for the two types of I-O income multipliers are:

$$\text{Type I} = \frac{\text{direct effect(\$)} + \text{indirect effect(\$)}}{\text{direct effect(\$)}}$$

$$\text{Type II} = \frac{\text{direct effect(\$)} + \text{indirect effect(\$)} + \text{induced effect(\$)}}{\text{direct effect(\$)}}$$

A simple examination of these relationships reveals that a high value for a Type I multiplier would indicate that a significant indirect effect is present, which in turn indicates a high degree of industrial sector interdependence. A Type II multiplier that is significantly greater than its companion Type I means that there is a high induced effect.

Projected Impact on West Virginia

Income. Due to the necessarily limited scope of this study, it was not possible to generate new I-O data. An existing I-O model was used, therefore, to estimate the projected effect on West Virginia income resulting from expanded wood energy use in the state. Two such models were considered for use: the Regional Industrial Multiplier System (RIMS) developed by the Bureau of Economic Analysis (BEA), and the 1975 West Virginia Input-Output Study.

The former was not selected for use for several reasons; among these were the fact that RIMS is based on secondary data sources, with the basic information about the technical requirements of industries coming from the most recent (1967) BEA national I-O model. The RIMS multiplier-estimating procedure regionalizes columns from that I-O model, using 1973 BEA county earnings data and 1973 County Business Patterns SIC county data. Another reason for bypassing RIMS in this study is that all multipliers are broken out according to BEA Economic Areas. These areas generally center around a Standard Metropolitan Statistical Area (SMSA) and in no way conform to state boundaries. That is, any given BEA area might include portions of several states. In fact, for West Virginia, nine different areas are represented, only two of which are wholly contained in the state (revised 1977 BEA economic areas). Thus it is difficult to analyze West Virginia as an economic region using the RIMS data.

The most persuasive reason for declining use of the RIMS model, however, is that the 1975 West Virginia I-O Study is available. This study is an update of the original 1965 report entitled Simulating Regional Economic Development which developed the first West Virginia I-O model. Both the 1965 and 1975 versions utilized primary data; that is, surveys were conducted to generate the transactions table and resulting sector multipliers.

Certain precautions should be observed in interpreting the rather simplistic economic impact estimates that follow in this section. Primarily, it is important to keep in mind that these figures can be considered only as estimates. The "industry" proposed for expansion in this study (the production of fuelwood) really is not an existing industrial sector. In fact, it can hardly be considered an industry at this time. The sector chosen for use from among the 48 disaggregated in the West Virginia I-O model (sector 14: logging and sawmills) is thus considered to be the best available match for estimating the potential effects of increased expenditures in this fledgling industry. It could prove worthwhile to run a simulation using fuelwood production as a separate sector in this model. Such a step is, however, beyond the scope of this study.

The other important point to be aware of is that inherent in the following analysis is the assumption that the expanded use of wood as a fuel will replace a corresponding level of fossil fuel energy (primarily oil and natural gas) that is currently being imported from out of state. Since no projection is made for possible higher industrial energy requirements resulting from increases in state industrial activity, this is the only way that in-state expenditures could increase and thereby instigate a multiplied income effect in West Virginia due to expanding wood energy use. In other words, dollars now leaving the state for fossil fuels would remain to purchase wood energy.

It was estimated in Chapter III of this study (see Figure III-11) that approximately 7.8 million tons is the realistic quantity of energy wood available for annual recovery out of about 34 million tons identified as being theoretically available. The costs incurred in the harvesting and delivery of fuelwood were estimated in Chapter IV. The three areas that would experience increased demand are stumpage rights (the purchased right to harvest from woodlot owners), harvesting, and transportation. An average stumpage price of $1.20/ton was presented in Chapter III. The average harvesting cost used here was derived from data in Table IV-4, which pertains to a skidding system. This was calculated by subtracting out one-half of the Profit and Taxes cost category, representing the tax portion. Income taxes would not be appropriate to include in expenditures undergoing a multiplier effect since the funds are in effect being removed from circulation.

For the hillside operation, then, the harvesting and transportation costs that will be used are:

$$\$23.65 - .5\ (\$2.95) \text{ or } \$22.18/\text{ton}.$$

For the flatland operation:

$$\$14.21 - .5\ (\$1.85) \text{ or } \$13.29/\text{ton}.$$

Combining the two in the same proportion as stipulated in Table IV-4 would yield:

$$.8\ (\$22.18) + .2\ (\$13.29) \text{ or } \$20.40/\text{ton}$$

This figure represents the average cost for harvesting and transporting one ton of fuelwood under typical terrain conditions. Note that the transportation cost is based on an average truck haul of 50 miles (one way).

If the entire realistic quantity of energy wood available were recovered, 7.8 million tons, and trucked to fuel customers, then the total annual expenditure made by these users would be:

($1.20 + $20.40) x 7,800,000 or $168,480,000.

To estimate the effect on state income, the Type II multiplier for the logging and sawmill sector is applied to this expenditure. The appropriate multiplier from the 1975 I-O study is 1.73. A rough estimate of the annual impact on state income, therefore, would be:

1.73 x $168,480,000 or approximately $291,470,000.

Several other points should be made here. The wood fuel would be an input to the production of the industries that do, in fact, convert to wood energy. While Chapter VI describes possible industrial applications for fuelwood, no confident prediction can be made as to which industrial sectors would convert or what the ultimate wood energy usage rate would be in any given sector. Table VI-2 indicates that the chemicals, primary metals, and stone, clay, and glass industries account for 94% of total industrial energy usage. The chemicals and stone, clay, and glass industries in particular make rather heavy use of natural gas and, therefore, would appear to be possible candidates for conversion to wood gas.

Another point to consider is that no allowance has been made for the increased capital investment expenditures that would result from industries converting their fuel-burning systems to accommodate wood. Since there is no clearly rational way to estimate the extent of such expenditures, they are not considered in the analysis. This would have the result of somewhat understating the total effect on income of increased wood fuel utilization and, therefore, could be considered a conservative assumption. Of course, only expenditures that would not have been made otherwise should be included in the multiplier effect, and a certain amount of capital reinvestment would be required over time anyway as equipment aged beyond its useful life. So the only additional investment conversion costs that should be included would be the incremental amount over what would have been spent for normal replacement and expansion.

The final point involves the schedule for phasing in wood fuel use. It is not practical to assume that the entire realistic quantity of energy wood available could be recovered in a short period of time, much less immediately. In fact, it could very well take 10 years or more of gradually increasing wood fuel utilization before attaining that level. If a 10-year period were assumed, with a linear increase in utilization, the income impact schedule would be:

1st year:	$21.60	x	780,000	tons	x	1.73	or	$ 29.15	million
2nd year:	"	x	1,560,000	"	x	"	"	58.29	"
3rd year:	"	x	2,340,000	"	x	"	"	87.44	"
4th year:	"	x	3,120,000	"	x	"	"	116.59	"
5th year:	"	x	3,900,000	"	x	"	"	145.74	"
6th year:	"	x	4,680,000	"	x	"	"	174.88	"
7th year:	"	x	5,460,000	"	x	"	"	204.03	"
8th year:	"	x	6,240,000	"	x	"	"	233.18	"
9th year:	"	x	7,020,000	"	x	"	"	262.32	"
10th year:	"	x	7,800,000	"	x	"	"	291.47	"

In 1976, the total personal income in West Virginia was about $9.94 billion. The potential income impact of $291.47 million would thus represent a 2.9% increase in total income. The corresponding 1976 per capita income of $5,394 would therefore be increased to $5,550.

Employment. The expanded utilization of wood as a fuel will create a number of new jobs. These jobs will supply the labor input necessary to satisfy the increased demand for wood fuel. The jobs will be both direct, that is, involved with the actual harvesting and delivery of wood, and indirect, or in industries that must increase production to supply the expanding wood energy industry.

The 1965 West Virginia I-O study produced employment multipliers for the 48 industrial sectors it identified. These multipliers essentially reflected the projected increase in required man hours for each additional dollar of production or expenditure. The revised 1975 I-O study, due to budgetary constraints, was not able to update these multipliers, although their values were projected to 1975.

For a number of reasons this report did not make use of the 1965 I-O study's employment multipliers. These reasons primarily have to do with two facts: the logging and sawmill sector for which a multiplier is available is not a perfect match for a fuelwood industry in terms of required input, and these multipliers are quite old and are not easily adjusted for inflation.

Table IV-4 indicates representative estimates for hillside and flatland harvesting (by skidding). It shows, for hillside harvesting, that a crew of 10 men should be able to produce 18 tons of fuelwood per hour. Similarly, a flatland operation would have a crew of five men producing 20 tons per hour. Assuming 40 hours of production time per week for 50 weeks of the year, 2,000 annual production hours would yield 36,000 tons per year for a hillside crew and 40,000 tons per year for a flatland crew. Using the factors adopted in the table of 80% harvesting to be on hilly terrain and 20% on flatlands, the weighted average production would be approximately 36,800 tons/year from an average size crew of nine men.

If the entire realistic quantity of energy wood available, 7.8 million tons, were harvested, then 7,800,000/36,800 or 212 crews of nine men each should be required for direct harvesting operations. This would be a total of 212 x 9 or 1,908 new direct jobs.

The other job increase category that can be estimated here is the additional truck drivers necessary to transport the increased production to the end user (or perhaps to a rail or barge connection for further transportation). An average truck payload of wood chips would weigh approximately 25 tons. Thus, to support a harvesting crew producing 36,800 tons/year, 1,472 round trips would be required. If the average one-way haul is 50 miles, then a typical round trip would take about four hours, including loading and unloading time. The total man hours of truck driver time required to support each crew would then be 1,472 x 4 or 5,888 hours per year. At 2,000 hours per man per year, 2.94 additional truck driving jobs would be necessary for each nine-man harvesting crew. Considering the 212 crews calculated above to be a representative figure, then 212 x 2.94 or 624 new driving jobs would be created.

This analysis indicates that, so far, a total of 1,908 + 624 or 2,532 new direct jobs will have been created to support the expanded use of wood as a fuel. Without some sort of I-O employment multiplier, harvesting and transportation are the only areas that can be quantified in a study of this scope. A number of other direct jobs also will be created in a variety of different areas, such as harvesting equipment sales and service representatives, trucking schedulers and other administrative personnel, and managers responsible for ordering, receiving, storing, and handling wood fuel at industrial plant sites.

In addition, a number of jobs will be created that would be considered indirect to the harvesting and delivery process. These would include such positions as production workers for manufacturing harvesting equipment, construction workers involved in plant conversions, production workers for manufacturing wood burning and handling equipment, and even workers for support service industries, such as fast food restaurants and the insurance business.

Based on 1977 figures, the annual average total labor force in West Virginia was about 713,000, while the unemployment percentage was 5.9, or about 42,000. The projected additional new 2,532 direct jobs, therefore, would represent a 6% decrease in that unemployment figure. This assumes, of course, that all newly generated jobs would be filled by currently unemployed in-state workforce members. Naturally, there would be a number of workers who would simply switch jobs to one of those newly created. If they were from West Virginia, there would still be the net increase of 2,532 direct jobs. If workers from out of state occupied some of these positions, there would be a corresponding decrease in the impact on state unemployment.

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44 Fed. Reg. 3274, 16 January 1979.

Appendix A

DEFINITIONS OF FOREST SERVICE TERMS
NONCOMMERCIAL SPECIES IN THE NORTHEAST

Appendix A

Definitions of Forest Service Terms

LAND AREA CLASSES

Forest Land: Land that is at least 16.7% stocked (contains at least 7.5 square feet of basal area) by forest trees of any size, or that formerly had such tree cover and is not currently developed for non-forest use.

Commercial forest land: Forest land that is producing or capable of producing crops of industrial wood (more that 20 cubic feet per acre per year) and is not withdrawn from timber utilization. (Industrial wood: all round wood products except fuelwood.)

TREE CLASSES

Forest Trees: Woody plants that have a well developed stem and usually are more than 12 feet in height at maturity.

Growing-stock trees: All live trees of commercial species except rough and rotten trees.

Rotten trees: Live trees of commercial species that do not contain at least one 12-foot sawlog or two non-contiguous sawlogs, each 8 feet or longer, now or prospectively, and do not meet regional specifications for freedom from defect primarily because of rot; that is, when more than 50% of the cull volume in a tree is rotten.

Rough trees: The same as above except that rough trees do not meet regional specifications for freedom from defect primarily because of roughness or poor form; and, all live trees of non-commercial species.

CLASSES OF TIMBER

Softwoods: Coniferous trees that are usually evergreen, having needles or scalelike leaves.

Hardwoods: Dicotyledonous trees that are usually broad-leaved and deciduous.

Sawtimber trees: Live trees of commercial species (a) that are of the following minimum diameters at breast height -- softwoods 9.0" and hardwoods 11.0", and (b) that contain at least one 12-foot or two noncontiguous 8-foot merchantable sawlogs and meet regional specifications for freedom from defect.

CLASSES OF TIMBER (Continued)

Poletimber trees: Live trees of commercial species that meet regional specifications of soundness and form, and are at least 5.0" dbh but are smaller than sawtimber size.

Saplings: Live trees of commercial species that are 1.0" to 5.0" in diameter at breast and of good form and vigor.

Seedlings: Live trees of commercial species that are less than 1.0" in diameter at breast height and are expected to survive.

TIMBER MEASUREMENT AND VOLUME

Diameter at breast height (dbh): The diameter outside bark of a standing tree measured at 4½ feet above the ground.

Growing stock volume: Net volume, in cubic feet, of live growing-stock trees that are 5.0" dbh and over, from a 1-foot stump to a minimum 4.0" top diameter outside bark of the central stem, or to the point where the central stem breaks into limbs. Net volume equals gross volume less deduction for rot and/or sweep and crook.

Sawlog: A log meeting minimum standards of diameter, length, and defect, including logs at least 8 feet long, sound and straight, and with a minimum diameter inside bark for softwoods of 6" (8" for hardwoods) or other combinations of size and defect specified by regional standards.

ANNUAL NET GROWTH AND TIMBER REMOVALS

Average annual net growth: The change (resulting from natural causes) in net volume during the period between surveys, divided by the number of years in the period. Components of annual net growth include the increment in net volume of trees present at the beginning of the period and surviving to its end, plus net volume of trees that attain the minimum size to enter the class during the period, minus the net volume of trees that died during the period, minus the net volume of trees that became rough or rotten trees during the period.

Average annual mortality: The net volume of sound wood removed from the class because of death from natural causes during the period between surveys, divided by the number of years between surveys.

Average annual removals: The net volume of trees harvested or killed in logging, cultural operations such as timber-stand improvement, land-clearing, or changes in land use during the period between surveys, divided by the number of years between surveys.

ANNUAL NET GROWTH AND TIMBER REMOVALS (Continued)

Current annual net growth, removals, and mortality: The estimated level of annual growth, removals, and mortality on commercial forest land during the year of the most recent inventory (1974 for West Virginia).

Logging residues: The unused growing-stock volume of trees cut for products; the total growing-stock volume of trees destroyed in the course of logging but not removed for products.

Other removals: The growing-stock volume of trees that were removed from the inventory (and not used for products) by cultural operations (weeding, thinning, etc.), land clearing, and reclassification of some commercial forest land as noncommercial forest land.

Manufacturing residues: Wood material incidentally produced in the manufacture of timber products but not utilized.

Roundwood products: Logs, bolts, or other round sections cut from growing stock or nongrowing stock for industrial or nonindustrial uses.

F.S. Code	NONCOMMERCIAL SPECIES IN THE NORTHEAST	
313	Boxelder	Acer negundo
315	Striped maple	A. pensylvanicum
319	Mountain maple	A. spicatum
340	Ailanthus	Ailanthus altissima
379	Gray birch	Betula populifolia
391	American hornbeam	Carpinus caroliniana
422	Allegheny chinquapin	Castanea pumila
450	Catalpa	Catalpa species
471	Eastern redbud	Cercis canadensis
500	Hawthorn	Crataegies species
581	Carolina silverbell	Halesia carolina
641	Osage-Orange	Maclura pomifera
660	Apple species	Malus species
680	Mulberry species	Morus species
701	Eastern hophornbeam	Ostrya virginiana
711	Sourwood	Oxydendrum arboreum
721	Redbay	Persea borbonia
761	Pin cherry	Prunus pensylvanica
816	Bear oak	Quercus ilicifolia
824	Blackjack oak	Q. marilandica
931	Sassafras	Sassafras albidum
999	Downy serviceberry	Amelanchier arborea
999	Pawpaw	Asimina triloba
999	Fringetree	Chionanthus virginicus
999	American mountain-ash	Sorbus americana
999	Common sweetleaf	Symplocus tinctoria

Source: Northeast Forest Experiment Station, Upper Darby, PA.

Appendix B

REGIONS AND SURVEY UNITS FOR COUNTIES
SUMMARY OF COMPONENTS FOR ENERGY WOOD EQUATION

WEST VIRGINIA

County	P&D Region	Survey Unit*	County	P&D Region	Survey Unit*
Barbour	7	NE	Monroe	1	S
Berkeley	9	NE	Morgan	9	NE
Boone	3	S	McDowell	1	S
Braxton	7	NE	Nicholas	4	S
Brooke	11	NW	Ohio	10	NW
Cabell	2	NW	Pendleton	8	NE
Calhoun	5	NW	Pleasants	5	NW
Clay	3	S	Pocahontas	4	NE
Doddridge	6	NW	Preston	6	NE
Fayette	4	S	Putnam	3	NW
Gilmer	7	NW	Raleigh	1	S
Grant	8	NE	Randolph	7	NE
Greenbrier	4	S	Ritchie	5	NW
Hampshire	8	NE	Roane	5	NW
Hancock	11	NW	Summers	1	S
Hardy	8	NE	Taylor	6	NE
Harrison	6	NE	Tucker	7	NE
Jackson	5	NW	Tyler	5	NW
Jefferson	9	NE	Upshur	7	NE
Kanawha	3	S	Wayne	2	NW
Lewis	7	NE	Webster	4	NE
Lincoln	2	NW	Wetzel	10	NW
Logan	2	S	Wirt	5	NW
Marion	6	NW	Wood	5	NW
Marshall	10	NW	Wyoming	1	S
Mason	2	NW			
Mercer	1	S			
Mineral	8	NE			
Mingo	2	S			
Monongalia	6	NW			

*NW = Northwestern
NE = Northeastern
S = Southern


HANCOCK
BROOKE
OHIO
MARSHALL
WETZEL
MONONGALIA
MARION
PLEASANTS
TYLER
PRESTON
MORGAN
WOOD
RITCHIE
DODDRIDGE
HARRISON
TAYLOR
MINERAL
BERKELEY
HAMPSHIRE
JEFFERSON
BARBOUR
TUCKER
GRANT
WIRT
LEWIS
MASON
JACKSON
ROANE
CALHOUN
GILMER
UPSHUR
HARDY
RANDOLPH
BRAXTON
PENDLETON
PUTNAM
CABELL
KANAWHA
CLAY
WEBSTER
NICHOLAS
POCAHONTAS
WAYNE
LINCOLN
BOONE
FAYETTE
GREENBRIER
MINGO
LOGAN
RALEIGH
SUMMERS
WYOMING
MONROE
McDOWELL
MERCER

West Virginia

SUMMARY OF COMPONENTS FOR ENERGY WOOD EQUATION
(in annual million tons, green)

Region	Net Growth	Timber Cut	Mortality	Logging Residues & Other Removals	ROUGH & ROTTEN Net Growth	ROUGH & ROTTEN Mortality	ROUGH & ROTTEN Timber Cut	Energy Wood
SOFTWOODS								
1	.108	.065	.017	.015	.035	.012	.012	.110
2	.206	.008	.033	.002	.018	.006	.006	.246
3	.125	.035	.020	.008	.024	.008	.008	.142
4	.577	.101	.094	.023	.073	.025	.025	.666
5	.363	---	.059	---	.026	.009	.009	.468
6	.144	.006	.023	.001	.010	.003	.003	.172
7	.648	.035	.105	.008	.046	.0154	.0154	.808
8	.742	.042	.120	.010	.053	.018	.018	.883
9	.142	.008	.023	.002	.010	.003	.003	.169
10	.040	---	.006	---	.003	.001	.001	.049
11	.006	---	.001	---	.005	.0002	.0002	.012
TOTALS	3.101	0.300	.501	.069	.303	.1006	.1006	3.725
HARDWOODS								
1	2.561	.731	.344	.302	.540	.154	.110	3.060
2	2.575	.400	.346	.165	.376	.107	.077	3.092
3	2.109	.535	.283	.221	.410	.117	.084	2.521
4	4.968	1.208	.666	.499	1.149	.329	.235	6.168
5	2.803	.273	.376	.113	.329	.094	.067	3.375
6	2.069	.297	.278	.122	.371	.106	.076	2.573
7	4.170	.785	.560	.325	1.000	.286	.204	5.352
8	2.087	.414	.280	.171	.528	.151	.108	2.695
9	.363	.072	.049	.030	.091	.026	.019	.468
10	.787	.077	.106	.032	.093	.026	.019	.948
11	.110	.011	.015	.005	.013	.004	.003	.133
TOTALS	24.602	4.803	3.303	1.985	4.900	1.434	1.002	30.385
GRAND TOTALS	27.703	5.103	3.804	2.054	5.203	1.535	1.103	34.110

Appendix C

DIRECTORY OF MANUFACTURERS OF HARVESTING EQUIPMENT AND SUPPLIES

APPENDIX C

Directory of Manufacturers of Harvesting Equipment and Supplies *

Arches, Logging

Cooper Corp., Howard, Box 3704, Portland, OR 97208
FLECO Corp., Box 2370, Jacksonville, FL, 32203
Young Corp., Box 3522, Seattle, WA, 98134
Young Industries, Inc., 3231 Utah St., Seattle, WA, 98134

Chainsaw, Chain and Accessories

Granberg Industries, 200 So. Gerrard Blvd., Richmond, CA, 94804
McCulloch Corp., Box 92180, L os Angeles, CA,90009
Omark Ind., Oregon Saw Chain Div., 9701 S. E. McLoughlin Blvd., Portland, OR, 97222
Stihl Inc., 5701 Thurston Ave., Virginia Beach, VA. 23455
Townsend Saw Chain Corp., Box 6396, Columbia, SC, 29260
Windsor Metal Prods, 3147 Thunderbird, Burnaby, B.C., Canada
Zip Penn Inc., Box 179, Erie, PA, 16512

Chain Saws, Portable

Allis Chalmers Corp., P. O. Box 512, Milwaukee, WI, 53201
Beaird-Poulan Col, Div. Emerson Electric, 5320 Greenwood Rd,. Shreveport, LA, 71109
Clinton Engine Corp., Clark & Maple, Maquoketa, IA, 52060
Chrysler & West Bend, Chrysler Outboard Corp., Hartford, WI,53207
John Deere Outside Mfd. Prods., Div., 909 Third Ave., Moline, IL. 61265.
Dolmar North American Corp., Box 1027, Monrovia, CA, 91016
Desa Ind., Power Prods. Div., 25000 SW Ave., Park Forest, IL, 60466
Echo Chain Saw Div., Kioritz Corp., 350 Wainwright, Northbrook, IL, 60062
Homelite Div. Textron Inc., Box 7047 Charlotte, NC, 28217
Husqvarna AB, 151 New World Way, Plainfield, NJ, 07080
Jonsereds Fabrikers AB, 1333 Matheson Blvd., Mississauga, ONT, Canada
Lancaster Chain Saw Dir., Lancaster Pump Inc., Lancaster, PA, 17604
LM Equip. Co., Inc., 9705 SE 13th Ave., Portland, OR 97202
Lombard-Campbell Hausfeld, Div., Scott & Fetzer, Harrison, OH 45030
McCulloch Corp., 6101 W. Century Blvd., Los Angeles, CA, 90045
Mono Mfg. Co., 540 E. Commercial, Springfield, MO, 65803
Montgomery Ward, 2825 E. 14th St., Oakland, CA, 94606
Partner Industries, 255 E. Industry Ave., Frankfort, IL, 60423
Pioneer Saws, Div., OMC-Lincoln, P. O. Box 82409, Lincoln, NB, 68501
Roper Corp., Broadway & Schuyler, Bradley, IL, 60915
Scotsman-Scotsco, 9180 SE 74th Ave., Portland, OR, 97206
Sears Roebuck & CO. 2650 E. Olympic Blvd., Los Angeles, CA, 90051
Skil Corp., 5033 Elston Ave., Chicago, IL 60630
Solo Motors Inc., P.O. Box 5030, Newport News, VA 23605

*Source: "Handbook for Eastern Timber Harvesting," Fred C. Simmons, USFS Pub., 1979

Chain Saws, Portable (continued)

Stihl Inc., 5701 Thurston Ave., Virginia Beach, VA, 23455
Thomas Industries, Wright Saw Div., 207 E. Broadway, Louisville, KY, 40202
Wright-Bernet Inc., 1524 Bender Ave. Hamilton, OH, 45100

Chains, Tire

Canadian Chains Inc., Box 428, Skowhegan, ME, 04976
Fruehauf Corp., 10900 Harper Ave., Detroit, MI, 48238
Millards Mach, Rt. #3, Box #3, Martinsville, VA, 24112
Wire Rope Fittings, 535 Means St., Atlanta, GA, 30318

Chippers, Mobile

Black Clawson, P. O. Box 1028, Everett, WA, 98206
H. Jack Flanders Co., 221 Fausset Plaza, Little Rock, AR, 72205
Forano Ltd., 7000 Park Ave., Montreal, Quebec, Canada
Fulghum Industries, Wadley, GA, 30477
Kockums Industries, Box 108 Trussville, AL, 35173
Morbark Industries, Box 97, Winn, MI, 48896
Nicholson Mfg. Co., 3680 E. Marginal Way, Seattle, WA, 98134
Precision Chipper Corp., Box 360, Leads, AL, 35094
Strong Mfg. Co., 489 Eight Mile Rd., Remus, MI, 49340
Valon Kone, 1789 Ellsworth Ind. Blvd., Atlanta, GA, 30318

Culverts & Pine

ARMCO Steel Corp., 703 Curtis St., Middletown, OH, 45042
Bethlehem Steel Corp., Bethlehem, PA, 18016
Kaiser Agricultural Chemicals, Box 246, Savannah, GA, 31402
Owens-Corning Fiberglass Corp., Fiberglass Tower, Toledo, OH 43659
Pacific Corrugated Culvert Corp., Box 3, Redding, CA 96001
U. S. Steel Corp., 600 Grant St., Pittsburgh, PA, 15230

Crawler Conversion Kit (for wheel tractors)

Arps Corp., Wisconsin Ave., New Holstein, WI, 53230

Delimbers

Copland Mfg. Co., 2075 Exchange St., Montgomery, AL, 36111
S. Huot, 990 St. Therese St., Quebec, P.Q., Canada
Jouppi Timber Machinery, Isabella, MN, 55600
Kockums Industries Inc., Box 108, Trussville, AL, 35173
National Hydroax, Owatonna, MN 55060
Timmins Mfg., Ltd., P.O. Box 497, Timmins ONT, Canada

Explosives

Atlas Powder Co., 2700 Park Central PL., Dallas, TX, 75251
Dupont de Nemours & Co., E.I., Wilmington, DE, 19898
Grace & Co., AG. Chem. Group, Box 277, Memphis, TN, 38101
Hercules Inc., 910 Market St., Wilmington, DE, 19899
Int. Minerals & Chem. Corp., Trojan Div., 17 N. 7th St., Allentown, PA, 18105

Grapples and Tongs

Allen Hydraulics, Box 6706, Savannah, GA, 31405
Esco Corp., 2141 NW 25th St., Portland, OR, 97210
Barko Hydraulics, Box 6227, Duluth, MN, 55806
Harrington Mfg. Co., Lewiston, NC, 27849
Ingersoll-Rand Co., Tool & Hoist Div., E. Brunswick, NJ 08816
Little Giant Crane & Shovel, Box 4015, Highland Park, Des Moines, IA, 50333
Rome Industries, Box 48, Cedartown, GA, 30125
Skookum Co. Inc., Box 03099, Portland, OR, 97203
Snow & Neally Co., 155 Perry Rd., Bangor, ME, 04401
Uni-Tool Attachments, 1607 Woodland Ave., Columbus, OH, 43219
Washington Iron Works, 1500 S. 6th St., Seattle, WA, 98134
Yaun Mfg. Co., 2120 N. Third St., Baton Rouge, LA, 70802
Young Corp., Box 3522, Seattle, WA, 98124

Harvesting Machines

Allen Hydraulics, Box 6706, Savannah, GA, 31405
Bush Manufacturing Co., Box 108, Trussville, AL, 35173
Caterpillar Tractor Co., 100 NE Adams St., Perioa, IL. 61602
Deere & Co., John Deere Rd., Moline, IL. 61265
Drott Mfg Co., Div. J. I. Case Co., Box 1087, Wassau, WI, 54401
Eaton Corp., Const. & Forrestry Eq. Div., Box 848, Woodstock, ONT, Canada
FMC Corp., Woodlands Eq. Div., 1105 Coleman Ave., San Jose, CA, 95108
Franklin Eq. Co., Box 69, Franklin, VA, 23851
Hahn Machinery Co., Box 299, Two Harbors, MN, 55616
International Harvester Co., 600 Woodfield Dr., Schaumburg, IL, 60172
Koehring-Waterous, Ltd., Market St., Brantford, ONT, Canada
Liebherr-America, Inc., 4100 Chestnut Ave., Newport News, VA, 23600
Morbark Industries, Inc., Winn, IM, 48896
Timberline Eq. Co., Box 1489, Houston, TX, 77001
Warner & Swasey Co., 31700 Solon Rd., Solon, OH, 44139

Loaders, Front End

Arps Corp., New Holstein, WI, 53601
Allis-Chalmers Corp., Box 512, Milwaukee, WI, 53201
Case Co., J.I., 700 State St., Racine, WI, 53404
Catepillar Tractor Co., 100 NE Adams St., Peoria, IL, 61602
Clark Eq. Co., Box 547, Benton Harbor, MI, 49022
Deere & Co., John Deere Rd., Moline, IL, 61265
Eaton Corp., Const. Eq. Div., Batavia, NY, 14020
Fiat-Allis, 3000 S. 6th St., Springfield, IL, 62710
Ford Motor Co., Tractor Div., 2500 E. Maple Rd., Troy, MI, 48150
General Motors Corp., Terex Div., Hudson, OH, 44236
International Harvester Co., 600 Woodfield Dr., Schaumburg, IL, 60172
Marathon Letourneau Co., Box 2307, Longview, TX, 75601
Massey-Ferguson, Inc., 1901 Bell Ave., Des Moines, IA, 50315
Melroe Mfg. Co., Gwinner, ND, 58040
Owatonna Mfg Co., Box 547, Owatonna, MN, 55060
Pettibone Corp., 4710 Division St., Chicago, IL, 60651
Raygo-Wagner Inc., Box 20044, Portland, OR, 97220
Taylor Machine Works, Box 150, Louisville, MS, 39339

Log Loaders, Cable

American Hoist & Derrick, 63 S. Roberts St., St. Paul, MN, 55107
Bucyrus-Erie Co., Box 56, S. Milwaukee, WI, 53172
Clark Eq. Co., Ind. Truck Div., 625 N. 24th St., Battle Creek, MI, 49016
Cooper Corp., Howard, Box 3704, Portland, OR, 97208
FMC Corp., Const. Eq. Div., 1201 SW 6th St., Cedar Rapids, IA, 52406
Harnischfeger Corp., Box 554, Milwaukee, WI, 53201
Koehring Co., Orain Div., 1374 E. 28th Ave., Lorain, OH, 44055
Northwest Engineering Co., 201 W. Walnut, Green Bay, WI, 54303
Skookim Co., Box 03099, Portland, OR, 97203
Smith-Berger Mfg Co., 3236 SW 16th Ave., Seattle, WA, 98134
Young Industries, 3231 Utah St., S. Seattle, WA, 98134

Log Loaders, Hydraulic

Barko Hydraulics, Box 6227, Duluth, MN, 55806
Burnette Machine Works, 150 E. Columbia St., New Westminster. B.C., Canada
Clark Eq. Co., Box 547, Benton Harbor, MI, 49022
Drott Mfg. Co., Box 1087, Wassau, WI, 54401
Dunham Mfg. Co., Minden, LA, 71055
Eaton Corp., Const. Eq. Div., Batavia, NY, 14020
Deere & Co., John Deere Rd, Moline, IL, 61265
Franklin Eq. Co., Box 697, Franklin, VA, 23851
Husky Hydraulics, Box 86, Two Harbors, MN, 55616
Jonsereds Ltd., 1333 Matheson Blvd., Mississaiga, ONT, Canada
Kockums Industries, Inc., Box 108, Trussville, AL, 35173
Koehring Co., Bantam Div., Waverly, IA, 50677
Lucky Mfg. Co., 103 Winchester Rd., Huntsville, Al, 35810
Omark Industries, Hydraulic Div., Box 946, Zebulon, NC 27597
Pettibone Corp., 4710 W. Division St., Chicago, IL, 60651
Savage Enterprises, Inc., Box 1321, Roseburg, OR 97470
Waldon, Inc., Fairview, OK, 73737

Logging Tools Axes = (1) Wdges = (2) Peaveys, cant hooks, pulp hooks = (3)

Collins Ax & Tool Co., (1), Lewiston, PA, 17044
Dominion Chain Co., (2,3), 617 Douro St., Stratford, ONT, Canada
Mann Edge Tool Co., (1,2), Water St., Lewistown, PA, 17044
Peavey Mfg. Co., (2,3), P.O. Box 371, Brewer, ME, 04401
Plumb, Fayette R., (1), 837 James St., Philadelphia, PA, 19137
Snow & Neally Co., (1,2,3), 155 Perry Rd., Bangor, ME, 04401
Walters Axe Co. Ltd., (1), 85 Front St., Hull, P. Quebec, Canada

Rigging Components, Logging

A-1 Steel & Iron Foundry Ltd., 1660 Station St., Vancouver, B.C., Canada
American Hoist & Derrick, The Crosby Group, Box 3128, Tulsa, OK, 74101
Cascade Loggers Supply, 230 Maryland Ave., Chehalis, WA, 98532
Eaton Corp, Forestry & Const. Eq. Div., Woodstock, ONT, Canada
ESCO Corp., 2141 NW 25th St., Portland, OR, 97210
Skookum Co., Inc., Box 03099, Portland, OR, 97203
Wire Rope & Fittings Co., Box 93524, Atlanta, GA, 30318
Young Corp., Box 3533, Seattle, WA, 98124

Rippers, Tractor

American Tractor Equip. Co., Box 1226, Oakland, CA. 94604
Caterpillar Tractor Co., 100 NE Adams St., Peoria, IL, 61602
ESCO Corp., 2141 NW 25th St., Portland, Or, 97210
Fiat-Allis Const. Mach. Inc., Box 1213, Milwaukee, WI, 53201
International Harvester Co., 600 Woodland Dr., Schaumburg, IL, 60172
North Carolina Eq. Co., Box 431, Raleigh, NC 27602

Skidders, Wheeled

Athey Products Corp., Box 669, Raleigh, NC, 27602
Can-Car Inc., 5710 Tulane Dr., SW, Atlanta, GA, 30336
Caterpillar Tractor Co., 100 NE Adams St., Peoria, IL, 61602
Clark Equip. Co., Forestry Dept., 2518 Rolling Pines Rd., Columbia, SC, 29210
Cooper Corp., Howard, Box 3704, Portland, Or, 97208
Deere & Co., John Deere Rd., Moline, IL, 61265
Dunham Mfg. Co., Box 430, Minden, LA, 71055
Eaton Corp., Forestry & Const. Eq. Div., Box 848, Woodstock, ONT, Canada
Franklin Eq. Co., Franklin, VA, 23851
Gafner Auto & Machine Co., 2301 9th Ave., Escanaba, MI, 49829
Garrett Enumclaw Co., 711 Hiwy, 410, Enumclaw, WA, 98022
International Harvester Corp., 600 Woodland Dr., Schaumburg, IL, 60172
Massey-Ferguson Inc., 1901 Bell Ave., Des Moines, IA, 50315
Pettibone Corp., 4700 W. Division St., Chicago, IL, 60651
Taylor Machine Works, Louisville, MS, 39339

Splitters, Log

Cornell Mach. Co., Laceyville, PA, 18623
Carthage Mach. Co., 571 West End Ave., Carthage, NY, 13619
Engineering Prods. Corp., 1525-28 E. Ellis St., Waukesha, WI, 53186
F W & Assocs., 1853 Airport Rd., Mansfield, OH, 44903
LaFont Corp., 1319 Town St., Prentice, WI, 54556
Mobark Industries, Box 1000, Winn, MI, 48896
Piqua Engineering, 234 First St., Piqua, OH, 45356
Precision Chipper Corp., P.O. Box 360, Leeds, Al, 35095
Sawmill Hydraulics Co., RR #1, Farmington, IL, 61531

Tractors, Crawler

Bombardier Ltd., Box 10, Valcourt, Quebec, Canada
Case, J.I., Const. Eq. Div., 700 State St., Racine, WI, 53404
Caterpillar Tractor Co., 100 NE Adams St., Peoria, IL, 61602
Fiat-Allis Const. Mach., Box 1213, Milwaukee, Wi, 53201
FMC Corp., Woodlands Eq. Op., 1105 Coleman Ave., San Jose, Ca, 95108
International Harvester Co., 401 N. Michigan Ave., Chicago, IL, 60611
Komatsu Ltd., 555 California St., San Francisco, CA, 94104
Massey-Ferguson Inc., 1901 Bell Ave., Des Moines, IA, 50315

Trailers, Logging

Bocats, Inc., Box 1021, Garden City, KS, 67846
Dorsey Trailers Inc., Elba, Al, 36323
Fruehauf Corp., 10900 Harper Ave., Detroit, MI, 48232
Kelsey-Hayes Co., Rockford, IL, 61105

Trailers, Logging (continued)

Nabors Trailers Inc., Box 979, Mansfield, LA, 71052
Page & Page Co., Box 447, Tulatin, OR, 97062
Pointer-Willamette Trailer Co., Box 46351, Seattle, WA, 98146
Reliance Truck & Trailer Co., 7911 St. Rosa St., Cotati, CA, 94928
Royal Industries, Peerless Div., Box 760, Paragould, AR, 72450
Schwartz Mfg. Co., Box 248, Lester Prairie, MN, 55323
Trailmobile Div. of Pullman Inc., 200 S. Michigan Ave., Chicago, IL, 60604

Tree Tippers

Great Eastern Enterprises, Bucksport, ME, 04416
Owatonna Tool Co., Owantonna, MN, 55060

Trucks, Logging (Highway & off-highway)

Diamond Red Trucks, Inc., 1331 W. Wash. Ave., Lansing, MI, 48910
Ford Motor Co., Truck Div., 29500 Plymouth Rd., Livonia, MI, 48150
FWD Corp., Clintonville, WI, 54929
Gen. Motors Corp., Chevrolet Div., 3044 W. Grand Blvd., Detroit, MI, 48202
Gen. Motors Corp., Truck Div., 660 So. Blvd. East, Pontiac, MI, 48053
Hendrickson Mfg. Co., 8001 W 47th St., Lyons, IL, 60534
International Harvester Co., 401 N. Mich. Ave., Chicago, IL, 60611
Kenworth Motor Truck Co., 8801 E. Marginal Way, Seattle, WA, 98108
Mack Trucks, Box M, Allentown, PA, 18105
Oshkosh Truck Co., 2300 Oregon St., Oshkosh, WI 54901
Peterbilt Motors Co., 38801 Cherry St., Newark, CA, 94560
White Motor Corp., Truck Group, Box 91500, Cleveland, OH, 44103

Winches and Accessories

Atlas Copco. Inc., 70 Demarest Dr., Wayne, NJ, 07470
Bendix-Skagit Corp., Box 151, Sedro-Wolley, WA, 98284
Black & Decker Mfg. Co., 701 E. Joppa Rd., Towson, MD
Braden Industries, 806 E. Dallas, Broken Arrow, OK, 74102
CARCO Winch Prods., 1400 N. 4th St., Renton, WA, 98055
Clark Eq. Co., Axle & Trans. Div., Box 31, Buchanan, MI, 49107
Gearmatic Co., Inc., 7400 132nd St., Surrey, B.C., Canada
Hyster Co., Box 2902, Portland, OR, 97208
Northeast Implement Corp., 651 Halsey Valley Road, Spencer, NY, 14883
Pacific Hoist Co., Box 42287, Portland, Or, 92710
Rome Industries, Box 48, Cedarton, GA, 30125
Sperry Vickers, Tulsa Div., 1401 Crooks Rd., Troy, MI, 48084
Triway Mfg. Co., 7819 Old Hwy, 199, Marysville, WA, 98270
Warn Industries, 19450 S. 68th Ave., Kent, WA, 98031

Wire Rope

ARMCO Steel Corp., 703 Curtis St., Middletown, OH, 45042
Bethlehem Steel Corp., Bethlehem, Pa, 18016
Broderick & Bascom Rope, 10440 Trenton Rt., St. Louis, MO, 63132
Leschen Wire Rope Co., 609 N. 2nd St., St. Joseph, MO, 64502
Macwhyte Wire Rope Co., 2906 14th Ave., Kenosha, WI, 53140
Union Wire Rope, 700 Roberts St., Kansas City, MO, 64125
US Steel Supply Div., US Steel Corp., 13535 Torrence Ave., Chicago, IL, 60633

Yarders, Cable

Bendix-Skagit Corp., Box 151, Sedro-Wooley, WA, 98284
Cal-Ore Machinery Co., Box 20038, Portland, Or, 97220
Cascade Loggers' Supply, 240 Maryland Ave., Chehalis, WA, 98532
Feenaughty Machinery Co., Box 13279, Portland, OR, 97208
Interstate Tractor & Eq., Terex Div., Box 2927, Portland, Or, 97208
Lamb-Grays Harbor Co., Blaine & Firman Sts., Hoquiam, WA, 98550
Reinhold Hinteregger, Villach, Austria
Skookum Co., Inc., Box 03099, Portland, Or, 97203
Smith-Berger Mfg. Co., 3236 SW 16th, Seattle, WA, 98134
Taylor Machine Works, Louisville, Ms, 39339
Trail Equipment Co., 5440 NE Columbia Blvd, Portland, Or, 97720
Tyee Machinery Co., Granville Island, Vancouver, B.C., Canada
Washington Iron Works, 1500 S. 6th Ave., Seattle, WA, 98132
Wyssen Skyline Cranes, Reichanback (Kandervalley) Switzerland

Appendix D

CHARACTERISTICS OF WOOD AS A FUEL

APPENDIX D

CHARACTERISTICS OF WOOD AS A FUEL

Properties of Wood Fuel

Typical dry softwoods have a heating value of approximately 9,000 Btu/lb. Dry hardwoods have a heating value of approximately 8,000 Btu/lb. Wood has a typical ultimate analysis as follows: carbon 51.4%, oxygen 41%, hydrogen 6%, ash 1.5%, and a proximate analysis as follows: volatile material 78.1%, fixed carbon 20.4%, and ash 1.5%. Sulfur content is essentially zero. Additional analyses of other wood samples are given in Table D-1.

Properties of wood fuel vary widely, however, chiefly due to its moisture content. Wood fuel also comes from a variety of sources, and the range of particle size and form produce variation in the bulk density. Table D-2 gives typical values.

Table D-2

PROPERTIES OF WOOD FUEL

Wood Fuel	Moisture Content, wet basis	Higher Heating Value, Btu per lb	Bulk Density lb/ft^3
Whole Tree Chips	50%	4,500	24.0
Dry Planer Shavings	13%	7,800	6.0
Green Sawdust	50%	4,500	20.0
Dry Sawdust	13%	7,800	11.5
Wood Pellets	10%	8,100	35.0

The specific gravity (oven dry, 0% M.C.) of unprocessed wood is approximately 0.65 and 0.45 for hardwoods and softwoods, respectively, hence their tendency to float in water.

Table D-1

ANALYSES OF WOOD AND WOOD ASH

	Pine Bark	Oak Bark	Oregon Hog Fuel	Fir Bark[1]	Spruce Bark[1]	Redwood Bark[1]
Wood Analyses (Dry Basis), % by wt						
Proximate						
Volatile matter	72.9	76.0	74.7	74.3	69.6	72.6
Fixed carbon	24.2	18.7	23.3	24.0	26.6	27.0
Ash	2.9	5.3	2.0	1.7	3.8	0.4
Ultimate						
H Hydrogen	5.6	5.4	5.7	5.8	5.7	5.1
C Carbon	53.4	49.7	53.9	52.2	51.8	51.9
S Sulfur	0.1	0.1	trace	trace	0.1	trace
$N_2 + O_2$ Nitrogen + Oxygen	38.0	39.3	38.4	40.3	38.6	42.6
A Ash	2.9	5.3	2.0	1.7	3.8	0.4
Heating Value Btu/lb	9030	8370	9120	8810	8740	8350
Ash Analyses, % by wt						
Silica as SiO_2	----	----	----	1.7	32.0	14.3
Iron as Fe_2O_2	----	----	----	3.2	6.4	3.5
Titanium as TiO_2	----	----	----	0.0	0.8	0.3
Aluminum as Al_2O_2	----	----	----	3.2	11.0	4.0
Manganese as Mn_2O_2	----	----	----	3.9	1.5	0.1
Calcium as CaO	----	----	----	60.8	23.3	6.0
Magnesium as MgO	----	----	----	3.0	4.1	6.6
Alkalies as Na_2O	----	----	----	10.4	10.4	25.0
Sulfate as SO_2	----	----	----	3.0	2.1	7.4
Chloride as Cl	----	----	----	0.4	trace	18.4
Carbonate as CO_2	----	----	----	11.3	7.0	14.0
Undetermined	----	----	----	----	----	----

Table D-1 (Continued)

	Pine Bark	Oak Bark	Oregon Hog Fuel	Fir[1] Bark	Spruce[1] Bark	Redwood[1] Bark
Ash Fusibility, °F						
Reducing						
Initial deformation	2180	2690	----	----	----	----
Softening	2240	2720	----	----	----	----
Fluid	2310	2740	----	----	----	----
Oxidizing						
Initial deformation	2210	2680	----	----	----	----
Softening	2280	2730	----	----	----	----
Fluid	2350	2750	----	----	----	----

[1]Salt-water stored

One of the drawbacks to unprocessed wood fuel is its high volume and low energy density. This has developed interest in drying and densifying wood to reduce storage, handling, and burning problems.

Moisture Content and Heating Value

Any discussion of moisture content must start with an explanation of the two bases of measurement.

Wet Basis. The moisture content of wood (M.C.) on the wet basis is the weight of water in a wood sample, divided by the weight of dry wood plus the weight of water:

$$\text{Moisture Content, \%} = 100 \left[\frac{\text{weight of water}}{\text{weight of dry wood + weight of water}} \right]$$

On this basis, a one-pound sample which is found to be 1/2-pound wood and 1/2-pound water upon drying and weighing has a moisture content of 50%.

Dry Basis. The M.C. of wood on the dry basis is the fractional water content or the weight of the water in the sample by the sample weight when dried:

$$\text{Moisture Content, \%} = 100 \left[\frac{\text{weight of water}}{\text{weight of dry sample}} \right]$$

Using the same example, a one-pound sample which is half water and wood by weight would have a wet weight of one pound, a dry weight of one-half pound, and a M.C., dry basis, of 100%.

Conversion of Moisture Content. To find wet basis from dry basis:

$$\text{Moisture Content, Wet} = 100 \left[\frac{\text{M.C. Dry}}{100 + \text{M.C. Dry}} \right]$$

To find dry basis from wet basis:

$$\text{Moisture Content, Dry} = 100 \left[\frac{\text{M.C. Wet}}{100 - \text{M.C. Wet}} \right]$$

The following conversion table covers the normally encountered range:

MOISTURE CONTENT

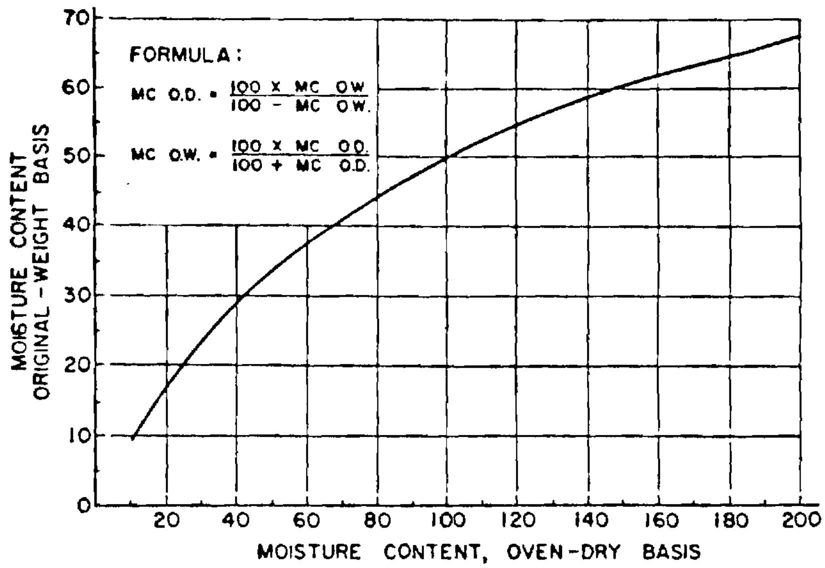
Wet Basis	Dry Basis
0%	0%
5%	5%
10%	11%
15%	18%
20%	25%
30%	43%
40%	67%
50%	100%
60%	150%

A reference chart for this conversion is included in Figure D-1.

The equilibrium water content of wood fuel varies with climate. Wood dries out naturally when left exposed to the air. Approximate average moisture content for wood which is not exposed to rainfall is 8%. The 8% figure corresponds to 45% relative humidity at 70°F. This average equilibrium moisture content is higher in the South and during the summer, and lower in the North and during the winter. One experiment with outside pile storage of sawdust and woodchips finds that significant natural drying occurs with only the first foot or so of the pile being affected by rainfall. The piles generated their own heat, with interior temperatures rising rapidly in the first 10 days to three weeks and leveling off at 130° to 190°F.

Figure D-1

MOISTURE CONTENT COMPARISON



The lower and higher heating value of wood (LHV and HHV, respectively) changes with its moisture content. The relationships between the higher heating value and moisture content (wet basis) can be expressed as follows:

$$\text{HHV (Btu/lb, actual)} = \text{HHV (oven dry)}(1-X)$$

where X is the fractional moisture content, wet basis. For example, a wood sample which has a HHV of 9,000 Btu/lb, oven dry, has a HHV of 4,500 Btu/lb at 50% M.C., and 6,750 Btu/lb at 25% M.C.

The HHV can be converted to LHV by the following formula:

$$\text{LHV} = \text{HHV} - 9{,}460\,(X_{H_2}) - 1{,}059\,(X_{H_2O})$$

where

X_{H_2} is the fraction of hydrogen

and

X_{H_2O} is the fraction of water found by ultimate analysis.

For a wood sample with ultimate analysis 50% water, 3% hydrogen, and HHV 4,500 Btu/lb (@ 50% M.C.), the LHV is 3,687.

The HHV of a fuel is easily found in the lab using a bomb calorimeter. The LHV is more difficult to find as it assumes that the products of combustion are cooled to their initial temperature, but that the water vapor is not condensed. When comparing fuels with little hydrogen, fuel efficiency will not differ appreciably using LHV or HHV. The LHV is a better standard for comparing the true efficiency of high-hydrogen fuels. The HHV, however, is the generally accepted standard because it is easily found in the lab.

Ash and Other Residue

The ash content of wood is remarkably low, usually in the range of 0.5%. This value may be as high as 5% if sand and grit from logging operations are not separated from the wood fuel. In wood residue from sawmills and other forest product plants, the ash content may rise due to decomposition of the wood which concentrates the ash. Careless removal of this waste wood with front-end loaders may add rock and soil to the wood fuel. Finally, foreign objects, such as tramp iron, tin cans, large rocks, etc., turn up frequently in larger wood-fueled systems. These must be detected and separated to keep them out of the combustion chamber.

The ash content of bark is higher than wood, and normally ranges from 2 to 8%. Agricultural residues such as bagasse from sugar cane typically contain 1.5% ash.

Ash removal systems vary with boiler or furnace type. With relatively clean, dry wood fuel, little ash is generated and manual deashing of the grates may be used on boilers up to 30,000 lb/hr steam capacity. Larger boilers and dirtier fuels call for automated handling of ash. The ash may be landfilled; however, it does have some value as a soil conditioner and is frequently high in potash concentration.

Light commercial and residential wood-fired systems suffer from creosote formation. Unlike ash which is removed from the firebox or escapes from the stack, creosote condenses and builds up on the inside of vent connectors and chimneys. Creosote is rarely found in large wood-fired equipment due to better control of combustion. Its hazards on smaller equipment are twofold. The first is blockage of the flue, resulting in decreased draft. The second is the potentially more hazardous occurrence of chimney fires. When the creosote is subjected to higher than normal temperatures it may ignite, sending flames and sparks out the top of the chimney. A poorly constructed or maintained chimney may fail under these high temperature conditions. The solution is inspection and mechanical cleaning of the flues to keep creosote and soot buildup at a safe level.

Properties of Low Btu Gas

Low Btu gas is produced by gasification or pyrolysis of wood. Gasifiers were used extensively to fuel internal combustion engines from the late 1800's until the end of WWII. Their primary potential application at the present time is to provide replacement fuel for gas/oil boilers.

Fixed bed updraft gasifiers are a primary candidate for gasifying wood. Unlike the crossdraft and downdraft gasifier, they can use wet wood as a fuel feed. In the operation of an updraft gasifier, producer gas is formed by blowing a fixed bed of wood with a continuous stream of air and steam. The resulting gas is usually more than 50% nitrogen, yielding a low Btu gas in the range of 150 Btu/ft^3. Oxygen-blown gasifiers can produce a fuel gas of 300 Btu/ft^3. Low temperature updraft gasifiers may produce a gas with high tar content. This requires a scrubber for cooling and cleaning the gas. Burners which premix the tarry fuel gas with recycled stack gas which vaporizes the tars have been tried with some success. These eliminate the necessity for gas cleaning equipment. Although high equipment and fuel cost have slowed the reintroduction of this old technology, scarcity of liquid and gas fuels may help speed its commercialization.

The physical properties of the producer gas closely resemble that of nitrogen, its major constituent. Table D-3 gives a typical analysis of wood gas from updraft gasifier.

The gas properties will vary with the rate of steam addition, temperature of the bed, and analysis of the feed material. These variations, however, are small in comparison to the effect of moisture content in the wood. If wet wood is used as a fuel, large amounts of water vapor are present in the hot flue gas. This water vapor, plus that generated in burning hydrogen and methane, may condense in the flue system or upon start-up of a cold boiler.

Table D-3

ANALYSIS OF WOOD GAS FROM UPDRAFT GASIFIER

Analysis of Gas	Heat Value Btu/ft^3	Composition
Nitrogen	---	50%
Carbon Monoxide	322	20%
Carbon Dioxide	---	15%
Hydrogen	325	12%
Methane	1014	3%

High Heat Value - 134 Btu/scf, dry basis (overall gas value)
Gas Density - 60°F, 1 atm, 0.0711 lb/ft^3

The water vapor and tars may be removed by cooling and scrubbing the hot gas stream. This clean, cool gas is much easier to burn and is ideal as a fuel for internal combustion engines. However, two negative factors appear. First, thermal efficiency drops from 90 to 70%; secondly, tars and acids need to be disposed of that would normally be incinerated in the burner.

Low Btu burners must be specially designed to handle the increased volume of gas. Typical air-to-gas ratio for natural gas is 10.7:1, while producer gas is 1.2:1. If hot, tarry gas is burned, lines must be heated, and some burners have incorporated recirculation of hot combusted gas which premixes with the fuel gas to vaporize condensed tars. Close-coupled combustion of the hot gas produced from relatively dry wood feed will result in a stack gas volume that is not much higher than encountered with natural gas firing. In this case, the boiler capacity would not be derated.

General Comments on Design Considerations

Direct fired boilers and furnaces which use wood are generally larger in size than coal-fired units and much larger in size than gas/oil-fired equipment. The lower energy density (Btu/ft^3) of the fuel necessitates larger firebox size and large fuel handling equipment.

Since wood is much higher in volatile content than coal, more overfire air is needed to burn these gases in suspension. Fine wood material tends to burn in suspension, producing even higher rates of combustion in the free space above the grates. For these reasons and the higher gas volume produced by the presence of water vapor, volume of the furnace is usually larger than with coal-fired boilers. Preheating the overfire air using an air heater on the flue gas outlet aids in raising efficiency and promotes better combustion of green wood fuel.

Multi-fuel boilers which can burn oil, gas, coal, or wood frequently must be derated when run on wood, especially green wood. This problem of reduced capacity may not be a great one as boilers may run infrequently at full load and oil or gas can be fired over the wood fuel to carry the extra load. Dry, densified wood pellets have been burned in boilers without any reduction in capacity compared with coal firing.

Theoretical Flame Temperatures

The actual flame temperature produced by any fuel is difficult to predict. The theoretical (or adiabatic) flame temperature offers a more uniform basis for comparison. Calculation of this temperature assumes that the enthalpy of the fuel and air and the products of combustion are equal. For an approximate answer, the lower heating value of the fuel may be divided by the weight of the products of combustion multiplied by the mean specific heat of the products.

$$\text{Theoretical Flame Temperature} = \left[\frac{\text{Lower Heating Value (Btu/lb fuel)}}{\text{Sum of the products (lbs product/lb fuel) x Mean Specific heat (Btu/lb of products)}} \right]$$

The resulting temperature would occur if the flame was not being cooled by its surroundings and was burning completely at 0% excess air.

Table D-4 presents theoretical flame temperatures for fossil fuels and wood fuels.

Table D-4

THEORETICAL FLAME TEMPERATURES
OF FOSSIL AND WOOD FUELS

Fuel	Theoretical Flame Temp., °F
Natural Gas (100% Methane)	3,660
#2 Fuel Oil (140,000 Btu/gal)	3,770
Coal (High Bituminous A., AL)	3,830
Wood (Dry)	3,650
(50% M.C.)	2,720
Wood Gas (Dry, Analysis from Appendix Table D-3)	2,410
(From 50% M.C. Wood)	1,840

The actual flame temperature measured in a furnace is usually 1000 to 1500°F less than the theoretical flame temperature.

Table D-4 shows that dry wood will produce a flame which is close in temperature to that of fossil fuels. Wet wood, however, has a lower flame temperature. This can be raised several hundred degrees by using combustion air which is preheated by an air preheater heat exchanger. This heat exchanger would seem advisable on boilers burning green wood to maintain high enough combustion temperatures to keep the efficiency high without enlarging the convective section of the boiler.

Dry producer gas has a flame temperature considerably less than fossil fuels. This is primarily due to the dilution of the flue gas by nitrogen and carbon dioxide. Again, preheating of combustion air plus burning the gas hot with a close-coupled burner can boost the flame temperature.

The flame temperatures calculated for wet wood and wood gas produced from wet wood are low. This may not be a drawback for some applications, such as drying operations where fossil fuels would be burned at high rates of excess air to lower product gas temperatures.

Appendix E

REPRESENTATIVE CONVERSION EQUIPMENT MANUFACTURERS

Appendix E

REPRESENTATIVE CONVERSION EQUIPMENT MANUFACTURERS

Wood Densification Equipment and Pellet Sales

Company	Product
1. Agnew Environmental Products P. O. Box 1168 Grants Pass, OR 97526 (503) 479-3396	Densified Briquettes Briquetting Machinery
2. American Hoist & Derrick Co. 63 S. Robert St. St. Paul, MN 55107 (612) 228-4321	Wood Baling Machinery
3. Bio-Solar Research & Devel. Corp. P. O. Box 762 Eugene, OR (503) 686-0765 Contact: R. Gunnerman	Wood Pellets Pellet Systems
4. The Bonnot Company 805 Lake Street Kent, OH 44240 (216) 673-5829	Densified Log Extruders
5. California Pellet Mill Co. 1114 E. Wabash Avenue Crawfordsville, IN 47933 (317) 362-2600 Contact: Bruce Young	Pelletizing Machinery
6. John Deere Corporation Ottumwa, Iowa (515) 684-4641 Contact: Don H. Pettergill	Crop Residue Densifiers
7. Guaranty Performance Co., Inc. P. O. Box 748 Independence, KS (316) 331-0020 Contact: A. Livingston	Wood Pellets Pellet Systems
8. Landers Machine Co. 207 E. Broadway Fort Worth, TX 76104 (817) 336-5653	Pelletizing Machinery

Wood Densification Equipment and Pellet Sales (Continued)

Company	Product
9. Lehigh Forming Co., Inc. P. O. Box 799 Easton, PA 18042 (215) 258-0830	Pellet Systems
10. Papakube Corporation 931 E. Harbor Drive San Diego, CA 92101 (714) 286-7644 Contact: Gerald Welson	Extruder-Cuber
11. Pullman-Woodex, Inc. P. O. Box 133 Goldston, NC 27252 (919) 898-4861	Wood Pellet Sales
12. Reydco Trading P. O. Box 3545 Redding, CA 96001 (916) 347-5334	Extruded Logs & Machinery
13. SPM Group, Inc. 14 Inverness Drive, East Englewood, CO 80111 (303) 770-1201 Contact: Konrad Ruckstuhl	Wood Briquettes Briquetting Machinery
14. Sprout, Waldron & Co. 130 Logan Street Muncy, PA 17756 (717) 546-8211 Contact: Elmer Thomas	Pelletizing Machinery
15. Tennessee Woodex P. O. Box 10041 Knoxville, TN 37919 (615) 588-7411 Contact: M. Threlkeld	Wood Pellet Sales
16. TransArctic Air, Ltd. P. O. Box 11573 Vancouver, B.C., Canada (604) 683-1123 Contact: R. M. Pierson	Wood Briquette Sales Wood Briquette Systems

Wood Conveying, Handling, and Processing Equipment

Company	Product
1. Aeroglide Corp. 7100 Hillsborough Road Raleigh, NC 27602 (919) 851-2000 Contact: Paul Hankey	Residue & Chip Dryers
2. Air-O-Flex Equipment Co. 3030 E. Hennepin Ave. Minneapolis, MN 55413 (612) 331-4925	Truck Dumps
3. American Sheet Metal, Inc. P. O. Box 9 Tualatin, OR (503) 638-9611	Wood Handling & Conveying Systems
4. Archer Blower, Inc. 6200 SW Virginia Ave. Portland, OR 97201 (503) 246-7755	Wood Waste Conveyors
5. Bahco Systems, Inc. P. O. Box 48116 Atlanta, GA 30362 (404) 455-7722	Bark Drying Systems
6. BoCats, Inc. P. O. Box 1021 Garden City, KS 67846 (316) 275-7167	Live Bottom Chip Trailers
7. Bigelow Machinery Inc. 407 N. Columbia Blvd. Portland, OR 97470 (503) 289-7319	Wood Hogs
8. Black Clawson, Inc. P. O. Box 1028 Everett, WA 98206 (206) 258-3555	Wood Hogs Metal & Rock Separators
9. CEA Carter Day Company 500 73rd Avenue, N. E. Minneapolis, MN 55430 (612) 571-1000	Wood Handling Equipment
10. Clarke's Sheet Metal, Inc. Box 2428 Eugene, OR 97402 (503) 343-3395	Conveyors Screens

Wood Conveying, Handling, and Processing Equipment (Continued)

	Company	Product
11.	Detroit Stoker Co. 1510 E. First St. Monroe, MI 48161 (313) 241-9500	Pneumatic Conveyors Spreader Stokers
12.	Ederer Inc. P. O. Box 24708 Seattle, WA 98124	Rake Cranes Conveyors
13.	Elektroniikkayhtyma Oy SF-03100 Nummela, Finland U. S. Distributor: Totem Equipment Co. P. O. Box 3706 Seattle, WA 98124 (206) 762-9191	Metal Detectors
14.	Eriez Magnetics Erie, PA 16512 (814) 833-9881	Metal Separators
15.	FMC Corp., MHS Div. 3400 Walnut Street Colmar, PA 18915 (215) 822-0581	Conveyors, Dryers
16.	Fulghum Industries, Inc. S. Main Street, Drawer G Wadley, GA 30477 (912) 252-5223	Chippers Conveyors Sizing Equipment
17.	Goodman Equipment Corp. 4834 S. Halsted Street Chicago, IL 60609 (312) 927-7420	Wood Hogs
18.	Guaranty Performance Co., Inc. P.O. Box 748, 1120 E. Main Independence, KS 67301 (316) 331-0020	Dryers
19.	The Heil Co. 3000 W. Montana Milwaukee, WI 53201 (414) 647-3101	Dryers

Wood Conveying, Handling, and Processing Equipment (Continued)

Company	Product
20. Jacksonville Blow Pipe Co. P. O. Box 3687 Jacksonville, Fl 32206 (904) 355-5671	Wood Hogs
21. Jeffrey Mfg. Div. Processing Equipment Operations 500 East Moorehead St/Room 221 Charlotte, NC 28202	Wood Hogs Conveyors
22. K-Tron Corporation P. O. Box 548 Glassboro, NJ 08028 (609) 881-6500	Metering Conveyors
23. Kockums Industries, Inc. P. O. Box 108 Trussville, AL 35173 (205) 655-3261	Chippers
24. Lamb Incorporated 851 Beltline Hwy. Mobile, AL 36606 (205) 479-7401	Hogs Hammermills
25. M.E.C. Company Box 330/1402 W. Main Neodesha, KS 66757 (316) 325-2673	Dryers
26. Mardee, Inc. 3129 E. Washington Ave. Madison, WI 53704 (608) 244-3331	Wood Handling Systems
27. The McBurney Corporation P. O. Box 47848 Atlanta, GA 30362 (404) 448-8144	Fuel Preparation & Handling
28. McConnell Industries P. O. Box 26210 Birmingham, AL 35226 (205) 942-3321	Fuel Preparation & Handling
29. Mill Supply Co. Box 3748 Missoula, MT 59801 (406) 543-7197	Live Bottom Bins

Wood Conveying, Handling, and Processing Equipment (Continued)

	Company	Product
30.	Miller Hofft, Inc. P. O. Box 8560 Richmond, VA 23226	Bins Conveyors
31.	MoDo Mekan, Inc. Suite 300/2175 Parklake Dr., N.E. Atlanta, GA 30345 (404) 934-3151	Conveyors Reclaim Bins
32.	Munson Machinery Co., Inc. 210 Seward Ave. Utica, NY 13503 (315) 797-0090	Hogs Hammermills
33.	Nicholson Engineered Systems P. O. Box 11336 Fort Worth, TX 76109 (817) 338-1103	Conveyors
34.	Nicholson Manufacturing Co. 3670 E. Marginal Way, So. Seattle, WA 98134 (206) 682-2752	Wood Handling & Preparation
35.	Peerless Div. Royal Industries P. O. Box 760 Paragould, AR 72450 (501) 236-7254	Truck Dumps Chip Vans Self-Unloading Trailers
36.	Rader Systems, Inc. 2400 Poplar Ave./Suite 312 Memphis, TN 38112 (901) 761-3390	Pneumatic Conveyors Disc Screens
37.	Rens Manufacturing Co. P. O. Box 337 Crosswell, OR 97426 (503) 895-2172	Metal Detectors
38.	Rexnord 3400 Fern Valley Road Louisville, KY 40213	Conveyors
39.	Salem Hammermill Co. 2601 Industrial Dr/Box 148 Salem, VA 24153 (703) 389-8696	Wood Hogs & Hammermills

Wood Conveying, Handling, and Processing Equipment (Continued)

	Company	Product
40.	Schutte Pulverizer Co., Inc. 61 Depot Street Buffalo, NY 14240 (716) 855-1555	Hogs Hammermills
41.	Screw Conveyor Corporation 700 Hoffman Street Hammond, IN 46327	Wood Conveyors Truck Dumps
42.	Sprout-Waldron Division 130 Logan Street Muncy, PA 17756	Reclaim Systems
43.	Stearns-Roger P. O. Box 5888 Denver, CO 80217 (303) 758-1122	Wood Dryers
44.	Steelcraft Corp. Box 12408 Memphis, TN 38112 (901) 452-5200	Bins Conveyors
45.	Triple S Dynamics 1031 S. Haskell Dallas, TX 75223 (214) 821-9143	Conveyors Sizing Equipment
46.	Union Heating, Inc. 724 Walnut (Box 308) Edmonds, WA 98020 (206) 775-4588	Fuel Feeders
47.	West Salem Machinery 665 Murlark Street Salem, OR (503) 364-2213	Hogs Disc Screen

Wood Residue Storage Equipment

1. American Sheet Metal, Inc.
   P. O. Box 9
   Tualatin, OR 97062

2. Archer Blower, Inc.
   6200 SW Virginia Avenue
   Portland, OR 97201

Wood Residue Storage Equipment (Continued)

Company
3. Atlas Systems Corporation P. O. Box 11496 Spokane, WA 99211 (509) 535-7775
4. CEA Carter Day Co. 500 73rd Ave., N. E. Minneapolis, MN 55430 (612) 571-1000
5. Clarke's Sheet Metal, Inc. Box 2428 Eugene, OR 97402 (503) 343-3395
6. Gebr. Weiss KG c/o Energy Control Engineering Corp. P. O. Box 3064 Charlotte, N.C.
7. Laidig, Inc. 1320 S. Merrifield Ave. Mishawaka, IN (219) 256-0204
8. Miller Hoftt, Inc. P. O. Box 8560 Richmond, VA 23226 (703) 288-1937
9. Nicholson Engineered Systems P. O. Box 11336 Fort Worth, TX 76109
10. Peerless Division Royal Industries, Inc. P. O. Box 760 Paragould, AR 72150
11. Star Silo Co. R.D. 1 Myerstown, PA 17067 (717) 866-5708
12. Sprout Waldron 130 Logan Street Muncy, PA 17756 (717) 546-8211

Wood Residue Storage Equipment (Continued)

Company

13. Piedmont Silo Company, Inc.
    South Dearing Road
    Covington, GA 30209
    (404) 786-3031

14. Steelcraft Corp.
    Box 12408
    Memphis, TN 38112
    (901) 452-5200

15. Wellons, Inc.
    P. O. Box 381
    Sherwood, OR 97140
    (503) 625-6131

Wood-Fired Boilers - Moderate Sizes

1. Basic Environmental Engineering, Inc.
   21W161 Hill Street
   Glen Ellyn, Illinois 60137
   (312) 469-5340
   Contact: Mr. M. J. Adamski

2. Beech Island Steam, Inc.
   P. O. Box 681
   Clearwater, S. C. 28922
   (803) 593-5116

3. The Bigelow Company
   P. O. Box 706
   New Haven, Connecticut 06503
   (203) 772-3150

4. Combustion Service & Equipment Co.
   2016 Babcock Blvd.
   Pittsburgh, Pennsylvania 15209
   (412) 821-8900

5. Deltak Corporation
   P. O. Box 9496
   Minneapolis, Minnesota 55440
   (612) 544-3371

6. Industrial Boiler Co., Inc.
   P. O. Box 936
   Thomasville, Georgia 31792
   (912) 226-3024
   Contact: Mr. Welch Goggins

Wood-Fired Boilers - Moderate Sizes (Continued)

Company

7. E. Keeler Co.
238 W. Street
Williamsport, Pennsylvania 17701
(814) 326-3361

8. Ray Burner Co.
1301 San Jose Avenue
San Francisco, California 94112
(415) 333-5800

9. Gebr. Weiss K. G.
P. O. Box 660
D6340 Dillenburg
W. Germany

10. Wellons, Inc.
P. O. Box 381
Sherwood, Oregon 97140
(503) 625-6131
Contact: R. L. Nye

11. Zurn Industries
Erie City Energy Division
Erie, Pennsylvania 16503
(814) 542-6421

In addition, there are several other companies which specialize in building steam systems incorporating wood-fired package boilers:

1. Bumstead-Woolford Co.
P. O. Box 448
Woodinville, Washington 98072

2. The Gaskell Company, Inc.
P. O. Box 13225
Memphis, Tennessee 38113
(901) 775-3222

3. The McBurney Corporation
P. O. Box 47858
Atlanta, Georgia 30362
(404) 448-8144

4. The Perry Smith Co., Inc.
P. O. Box 8711
Chattanooga, Tennessee 37411
(615) 892-7130
Contact: Mr. W. P. Smith

Wood-Fired Boilers - Large Sizes

Company
1. The Babcock & Wilcox Company Power Generation Group Barberton, Ohio 44203
2. C-E Industrial Boiler Operations Combustion Engineering, Inc. Windsor, Connecticut 06095 (203) 688-1911
3. Detroit Stoker Company 1510 E. First Street Monroe, Michigan 48161 (313) 241-9500
4. Foster Wheeler Ltd. 81 Eastchester Ave. P. O. Box 3007 St. Catherines, Ontario
5. Gotaverden Energy Systems Ltd. 111 Railside Road/Suite 300 Toronto, Ontario M3A 1B2 (416) 441-2421
6. Riley Stoker Corporation P. O. Box 547 Worcester, Massachusetts 01613

Wood-Fired Fluidized Beds

1. Combustion Power Company, Inc.
   3146 Willow Road
   Menlo Park, California 94025
   (415) 324-4744
   Contact: Mr. D. R. Moody

2. Dorr-Oliver-Long
   174 West Street, South
   Orillia, Ontario, Canada

3. Energy Products of Idaho, Inc.
   P. O. Box 153
   Coeur d'Alene, Idaho 83814
   (208) 667-7481
   Contact: Mr. N. Sowards

Wood-Fired Fluidized Beds (Continued)

Company
4. Incinergy Systems Ltd. 402 West Pender Street Vancouver, B.C., Canada (604) 684-6013
5. Johnston Boiler Company Ferrysburg, Michigan 49409 (616) 842-5050
6. Thermal Processes, Inc. 507 Willow Springs Road La Grange, Illinois 60525 (312) 354-8771 Contact: J. L. Burgland
7. York-Shipley, Inc. P. O. Box 349 York, Pennsylvania 17405 (717) 755-1081 Contact: R. L. Lightner

Wood-Fired Pyrolysis and Gasification Systems

1. Applied Engineering
   1525 Charleston Highway
   Orangeburg, S. C. 29115
   (803) 534-2424
   Contact: Mr. Bob Clement

2. Dr. R. Bailie
   Dept. of Chemical Engineering
   University of West Virginia
   Morgantown, W. Virginia 26506

3. The Bio-Solar Corporation
   P. O. Box 762
   Eugene, Oregon 97401
   (503) 686-0765
   Contact: Mr. R. Gunnerman

4. The Biomass Corporation
   951 Live Oak Blvd.
   Yuba City, California 95901
   (916) 674-7230
   Contact: Dr. R. O. Williams

Wood-Fired Pyrolysis and Gasification Systems (Continued)

Company

5. B. C. Research
3650 Wesbrook Mall
Vancouver, B. C. V6S 2L2
Contact: Dr. D. W. Duncan

6. Canadian Industries Ltd.
P. O. Box 1657
Kirston, Ontario
(603) 544-1541
Contact: Mr. J. Kennedy

7. Davy Powergas, Inc.
6161 Savoy Drive
Houston, Texas 77036

8. DeKalb AgResearch, Inc.
DeKalb, Illinois 60115
(815) 758-3461
Contact: Stanley L, Bozdech

9. Moteurs Duvant
c/o IDP
One Old Country Road
Carle Place, N. Y.
(516) 248-0880
Contact: George Bonnici

10. Enerco, Inc.
Box 139A RD #1
Langhorne, Pennsylvania 19047
Contact: Miles Thomson

11. ERCO Company, Inc.
185 Alewife Brook Parkway
Cambridge, Massachusetts 02138
(617) 661-3111

12. Forest Fuels, Inc.
7 Main Street
Keene, New Hampshire 03431
(603) 352-2865
Contact: Mr. John Calhoun

13. Halcyon Associates, Inc.
The Halcyon, Maple Street
East Andover, New Hampshire 03231
(603) 735-5356
Contact: George Finnie

Wood-Fired Pyrolysis and Gasification Systems (Continued)

Company

14. Industrial Boiler Company
P. O. Box 936
Thomasville, Georgia 31792
(912) 226-3024

15. Industrial Combustion, Inc.
4465 N. Oakland Ave.
Milwaukee, Wisconsin 53211
(414) 332-4100

16. Dr. James Knight
Engineering Experiment Station
Georgia Institute of Technology
Atlanta, Georgia 30332

17. Mr. E. R. Mellenger
108 Carwarthen Street
Saint John, New Brunswick E2L 2N8
(506) 657-2764

18. Pioneer Hi-Bred International Inc.
1000 West Jefferson Street
Tipton, Indiana 46072
(317) 675-4587

19. University of California
Department of Agricultural Engineering
Davis, California 95616
(916) 752-1421
Contact: Dr. J. R. Goss

20. Westwood Polygas Ltd.
1444 Alberni Street
Vancouver, B. C. V6G 1A1
Contact: Mr. A. D. Fernie

Wood-Fired Suspension and Cyclone Burners

1. Coen Company, Inc.
1510 Rollins Road
Burlingame, CA 94010
(415) 697-0440

2. Energex Ltd.
P. O. Box 4208
Portland, Oregon 97208
(503) 286-8231
Contact: Mr. J. D. Parsons

Wood-Fired Suspension and Cyclone Burners (Continued)

Company

3. Guaranty Performance Co., Inc.
   1120 East Main
   Independence, Kansas 67301
   (316) 331-0020
   Contact: Mr. A. Livingston

4. McConnell Industries, Inc.
   P. O. Box 26210
   Birmingham, Alabama 35226
   (205) 942-3321
   Contact: Mr. Cliff McConnell

5. Peabody Gordon-Piatt, Inc.
   P. O. Box 650
   Winfield, Kansas 67156
   (316) 221-4770
   Contact: Mr. L. W. Halstead
   Atlanta: Mr. G. Norton (404) 981-4957

6. Waycot Systems Ltd.
   2940 Main Street
   Vancouver, B. C., Canada V5T 3G3
   (604) 876-6511
   Contact: Mr. J. Strath

7. York-Shipley Inc.
   P. O. Box 349
   York, Pennsylvania 17405
   (717) 755-1081
   Contact: Mr. R. Lightner

Other Wood Combustion Systems

1. Agnew Environmental Products
   P. O. Box 1168
   Grants Pass, Oregon 97256
   (503) 479-3396

2. American Fyr-Feeder Engineers
   1265 Rand Road
   Des Plaines, Illinois 60016
   (312) 298-0044

3. Biotherm Energy Systems, Inc.
   P. O. Box 1010
   Winn, Michigan 48896
   (517) 866-2381

Other Wood Combustion Systems (Continued)

Company	Products
4. Lamb-Cargate Industries, Ltd. 1135 Queens Avenue New Westminster, B. C., Canada (604) 521-8821 Contact: John Reid	
5. Olivine Corporation 1015 Hilton Avenue Bellingham, Washington 98225 (206) 733-3332	

Air Pollution Control Equipment

Company	Products
1. Aget Manufacturing Co. P. O. Box 248 Adrian, MI 49221 (517) 263-5781	Mechanical Collectors
2. American Air Filter Co., Inc. 215 Central Avenue Louisville, KY 40277	Baghouses
3. Anderson 2000 Inc. P. O. Box 20769 Atlanta, GA 30320 (404) 997-2000	Venturi Scrubbers
4. CEA Carter Day Company 500 73rd Ave., N. E. Minneapolis, MN 55430 (612) 571-1000	Mechanical Collectors
5. Clarke's Sheet Metal, Inc. Box 3428 Eugene, OR 97402 (503) 343-3395	Baghouses
6. Combustion Power Company, Inc. 1346 Willow Road Menlo Park, CA 94025 (415) 324-4744	Dry Collectors
7. Envirodyne, Inc. 10960 Wilshire Blvd. Los Angeles, CA 90024	

Air Pollution Control Equipment (Continued)

	Company	Product
8.	Enviro-Systems and Research, Inc. 2141 Patterson Ave. Roanoke, VA 24016 (703) 342-3171	Baghouses, Collectors
9.	Fisher-Klosterman, Inc. P. O. Box 11190, Sta. H. Louisville, KY 40211 (502) 776-1505 Contact: F. A. Graham	Wet Scrubbers
10.	FMC Corp. Environmental Equipment Div. 1800 FMC Drive West Itasca, IL 60143	
11.	Industrial Process Equip., Inc. P. O. Box 153 Lynnfield, MA 01940 (617) 245-0282	
12.	Mikro Pul Corp. 10 Chatham Road Summit, NJ 07901 (201) 273-6360	Baghouses
13.	Lear Siegler Environmental Technology Div. 74 Inverness Dr., East Englewood, CO 80110	
14.	Peabody Air Resources Equip. Co. P. O. Box 5202 Princeton, NJ 08540 (609) 443-5800	Wet Scrubbers
15.	Research-Cottrell P. O. Box 1500 Somerville, NJ (201) 685-4654 Contact: Wayne T. Hartshorn	Electrostatic Precipitators
16.	Torit Division Donaldson Co., Inc. P. O. Box 3217 St. Paul, MN 55165 (612) 698-0391	Cyclones, Baghouses

Air Pollution Control Equipment (Continued)

	Company	Product
17.	Western Precipitation Div. Joy Manufacturing Co. P. O. Box 2744, Terminal Annex Los Angeles, CA	Precipitators Mechanical Collectors
18.	Zurn Industries, Inc. Air Systems Div. P. O. Box 2206 Birmingham, AL 35201 (205) 252-2181	

Appendix F

1974 ENERGY CONSUMPTION IN THE MANUFACTURING AND TRANSPORTATION SECTORS OF WEST VIRGINIA*

*Source: "End Use Energy Consumption Data Base," U.S. Department of Energy, Energy Information Administration, Version 110, DOE/EIA-0175, Feb. 1979.

FUEL=COAL

YEAR	1974	1971	1967
USAGE	DIRECT HEAT-TOTAL	DIRECT HEAT-TOTAL	DIRECT HEAT-TOTAL
USER	ALL INDUSTRIES	ALL INDUSTRIES	ALL INDUSTRIES
CONSUMPTION	200.8 BILLION BTU	217.2 BILLION BTU	254.8 BILLION BTU
EXPENDITURES	$ 188.1 THOUSAND	$ 95.3 THOUSAND	$ 97.0 THOUSAND
YEAR	1974	1971	1967
USAGE	DIRECT HEAT-TOTAL	DIRECT HEAT-TOTAL	DIRECT HEAT-TOTAL
USER	PRIMARY METALS	PRIMARY METALS	PRIMARY METALS
CONSUMPTION	200.8 BILLION BTU	217.2 BILLION BTU	254.8 BILLION BTU
EXPENDITURES	$ 188.1 THOUSAND	$ 95.3 THOUSAND	$ 97.0 THOUSAND
YEAR	1974	1971	1967
USAGE	DIRECT HEAT-MISC.	DIRECT HEAT-MISC.	DIRECT HEAT-MISC.
USER	ALL INDUSTRIES	ALL INDUSTRIES	ALL INDUSTRIES
CONSUMPTION	200.8 BILLION BTU	217.2 BILLION BTU	254.8 BILLION BTU
EXPENDITURES	$ 188.1 THOUSAND	$ 95.3 THOUSAND	$ 97.0 THOUSAND
YEAR	1974	1971	1967
USAGE	DIRECT HEAT-MISC.	DIRECT HEAT-MISC.	DIRECT HEAT-MISC.
USER	PRIMARY METALS	PRIMARY METALS	PRIMARY METALS
CONSUMPTION	200.8 BILLION BTU	217.2 BILLION BTU	254.8 BILLION BTU
EXPENDITURES	$ 188.1 THOUSAND	$ 95.3 THOUSAND	$ 97.0 THOUSAND
YEAR	1974	1971	1967
USAGE	STEAM PRODUCTION	STEAM PRODUCTION	STEAM PRODUCTION
USER	ALL INDUSTRIES	ALL INDUSTRIES	ALL INDUSTRIES
CONSUMPTION	3475.0 BILLION BTU	1382.7 BILLION BTU	3179.1 BILLION BTU
EXPENDITURES	$ 3244.3 THOUSAND	$ 385.7 THOUSAND	$ 835.1 THOUSAND
YEAR	1974	1971	1967
USAGE	STEAM PRODUCTION	STEAM PRODUCTION	STEAM PRODUCTION
USER	PRIMARY METALS	PRIMARY METALS	PRIMARY METALS
CONSUMPTION	3475.0 BILLION BTU	1382.7 BILLION BTU	3179.1 BILLION BTU
EXPENDITURES	$ 3244.3 THOUSAND	$ 385.7 THOUSAND	$ 835.1 THOUSAND

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* FUEL=COAL *
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YEAR	1974	1971	1967
USAGE	ELECTRIC GERATION	ELECTRIC GERATION	ELECTRIC GERATION
USER	ALL INDUSTRIES	ALL INDUSTRIES	ALL INDUSTRIES
CONSUMPTION	4926.7 BILLION BTU	4702.6 BILLION BTU	5336.4 BILLION BTU
EXPENDITURES	$ 4661.4 THOUSAND	$ 1311.7 THOUSAND	$ 1401.7 THOUSAND

YEAR	1974	1971	1967
USAGE	ELECTRIC GERATION	ELECTRIC GERATION	ELECTRIC GERATION
USER	PRIMARY METALS	PRIMARY METALS	PRIMARY METALS
CONSUMPTION	4926.7 BILLION BTU	4702.6 BILLION BTU	5336.4 BILLION BTU
EXPENDITURES	$ 4661.4 THOUSAND	$ 1311.7 THOUSAND	$ 1401.7 THOUSAND

YEAR	1974	1971	1967
USAGE	COKE PRODUCTION	COKE PRODUCTION	COKE PRODUCTION
USER	ALL INDUSTRIES	ALL INDUSTRIES	ALL INDUSTRIES
CONSUMPTION	137665.0 BILLION BTU	117140.0 BILLION BTU	146144.0 BILLION BTU
EXPENDITURES	$ 160228.0 THOUSAND	$ 55977.0 THOUSAND	$ 43508.4 THOUSAND

YEAR	1974	1971	1967
USAGE	COKE PRODUCTION	COKE PRODUCTION	COKE PRODUCTION
USER	PRIMARY METALS	PRIMARY METALS	PRIMARY METALS
CONSUMPTION	137665.0 BILLION BTU	117140.0 BILLION BTU	146144.0 BILLION BTU
EXPENDITURES	$ 160228.0 THOUSAND	$ 55977.0 THOUSAND	$ 43508.4 THOUSAND

YEAR	1974	1971	1967
USAGE	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.
USER	ALL INDUSTRIES	ALL INDUSTRIES	ALL INDUSTRIES
CONSUMPTION	264219.0 BILLION BTU	211620.0 BILLION BTU	264414.0 BILLION BTU
EXPENDITURES	$ 229126.0 THOUSAND	$ 91433.3 THOUSAND	$ 72090.8 THOUSAND

YEAR	1974	1971	1967
USAGE	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.
USER	CHEMICAL	CHEMICAL	CHEMICAL
CONSUMPTION	54635.2 BILLION BTU	79321.9 BILLION BTU	95102.0 BILLION BTU
EXPENDITURES	$ 47399.3 THOUSAND	$ 23699.3 THOUSAND	$ 22064.9 THOUSAND

FUEL=COAL

YEAR	1974	1971	1967
USAGE	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.
USER	STONE, ETC.	STONE, ETC.	STONE, ETC.
CONSUMPTION	0.0 BILLION BTU	5371.8 BILLION BTU	6527.2 BILLION BTU
EXPENDITURES	$ 0.0 THOUSAND	$ 2700.0 THOUSAND	$ 2256.4 THOUSAND

YEAR	1974	1971	1967
USAGE	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.
USER	PRIMARY METALS	PRIMARY METALS	PRIMARY METALS
CONSUMPTION	148662.0 BILLION BTU	125855.0 BILLION BTU	160552.0 BILLION BTU
EXPENDITURES	$ 173449.0 THOUSAND	$ 58652.6 THOUSAND	$ 47278.5 THOUSAND

* FUEL=COKE *

YEAR	1974	1971	1967
USAGE	DIRECT HEAT-TOTAL	DIRECT HEAT-TOTAL	DIRECT HEAT-TOTAL
USER	ALL INDUSTRIES	ALL INDUSTRIES	ALL INDUSTRIES
CONSUMPTION	1825.2 BILLION BTU	1828.3 BILLION BTU	1980.7 BILLION BTU
EXPENDITURES	$ 1292.3 THOUSAND	$ 958.1 THOUSAND	$ 588.3 THOUSAND

YEAR	1974	1971	1967
USAGE	DIRECT HEAT-TOTAL	DIRECT HEAT-TOTAL	DIRECT HEAT-TOTAL
USER	PRIMARY METALS	PRIMARY METALS	PRIMARY METALS
CONSUMPTION	1825.2 BILLION BTU	1828.3 BILLION BTU	1980.7 BILLION BTU
EXPENDITURES	$ 1292.3 THOUSAND	$ 958.1 THOUSAND	$ 588.3 THOUSAND

YEAR	1974	1971	1967
USAGE	DIRECT HEAT-MISC.	DIRECT HEAT-MISC.	DIRECT HEAT-MISC.
USER	ALL INDUSTRIES	ALL INDUSTRIES	ALL INDUSTRIES
CONSUMPTION	1825.2 BILLION BTU	1828.3 BILLION BTU	1980.7 BILLION BTU
EXPENDITURES	$ 1292.3 THOUSAND	$ 958.1 THOUSAND	$ 588.3 THOUSAND

YEAR	1974	1971	1967
USAGE	DIRECT HEAT-MISC.	DIRECT HEAT-MISC.	DIRECT HEAT-MISC.
USER	PRIMARY METALS	PRIMARY METALS	PRIMARY METALS
CONSUMPTION	1825.2 BILLION BTU	1828.3 BILLION BTU	1980.7 BILLION BTU
EXPENDITURES	$ 1292.3 THOUSAND	$ 958.1 THOUSAND	$ 588.3 THOUSAND

YEAR	1974	1971	1967
USAGE	RAW MATERIAL PROD.	RAW MATERIAL PROD.	RAW MATERIAL PROD.
USER	ALL INDUSTRIES	ALL INDUSTRIES	ALL INDUSTRIES
CONSUMPTION	63059.2 BILLION BTU	64336.1 BILLION BTU	68270.6 BILLION BTU
EXPENDITURES	$ 233205.6 THOUSAND	$ 77851.9 THOUSAND	$ 46257.5 THOUSAND

YEAR	1974	1971	1967
USAGE	RAW MATERIAL PROD.	RAW MATERIAL PROD.	RAW MATERIAL PROD.
USER	PRIMARY METALS	PRIMARY METALS	PRIMARY METALS
CONSUMPTION	63059.2 BILLION BTU	64336.1 BILLION BTU	68270.6 BILLION BTU
EXPENDITURES	$ 233205.6 THOUSAND	$ 77851.9 THOUSAND	$ 46257.5 THOUSAND

* FUEL=COKE *

YEAR	1974	1971	1967
USAGE	STEAM PRODUCTION	STEAM PRODUCTION	STEAM PRODUCTION
USER	ALL INDUSTRIES	ALL INDUSTRIES	ALL INDUSTRIES
CONSUMPTION	104.8 BILLION BTU	81.6 BILLION BTU	259.9 BILLION BTU
EXPENDITURES	$ 74.2 THOUSAND	$ 42.8 THOUSAND	$ 77.2 THOUSAND

YEAR	1974	1971	1967
USAGE	STEAM PRODUCTION	STEAM PRODUCTION	STEAM PRODUCTION
USER	PRIMARY METALS	PRIMARY METALS	PRIMARY METALS
CONSUMPTION	104.8 BILLION BTU	81.6 BILLION BTU	259.9 BILLION BTU
EXPENDITURES	$ 74.2 THOUSAND	$ 42.8 THOUSAND	$ 77.2 THOUSAND

YEAR	1974	1971	1967
USAGE	ELECTRIC GERATION	ELECTRIC GERATION	ELECTRIC GERATION
USER	ALL INDUSTRIES	ALL INDUSTRIES	ALL INDUSTRIES
CONSUMPTION	148.2 BILLION BTU	276.3 BILLION BTU	436.3 BILLION BTU
EXPENDITURES	$ 104.9 THOUSAND	$ 144.8 THOUSAND	$ 129.6 THOUSAND

YEAR	1974	1971	1967
USAGE	ELECTRIC GERATION	ELECTRIC GERATION	ELECTRIC GERATION
USER	PRIMARY METALS	PRIMARY METALS	PRIMARY METALS
CONSUMPTION	148.2 BILLION BTU	276.3 BILLION BTU	436.3 BILLION BTU
EXPENDITURES	$ 104.9 THOUSAND	$ 144.8 THOUSAND	$ 129.6 THOUSAND

YEAR	1974	1971	1967
USAGE	COKE PRODUCTION	COKE PRODUCTION	COKE PRODUCTION
USER	ALL INDUSTRIES	ALL INDUSTRIES	ALL INDUSTRIES
CONSUMPTION	-95975.0 BILLION BTU	-79229.0 BILLION BTU	-98191.0 BILLION BTU
EXPENDITURES	$ -265600.0 THOUSAND	$ -92662.0 THOUSAND	$ -67472.0 THOUSAND

YEAR	1974	1971	1967
USAGE	COKE PRODUCTION	COKE PRODUCTION	COKE PRODUCTION
USER	PRIMARY METALS	PRIMARY METALS	PRIMARY METALS
CONSUMPTION	-95975.0 BILLION BTU	-79229.0 BILLION BTU	-98191.0 BILLION BTU
EXPENDITURES	$ -265600.0 THOUSAND	$ -92662.0 THOUSAND	$ -67472.0 THOUSAND

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* FUEL=COKE   *
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YEAR	1974	1971	1967
USAGE	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.
USER	ALL INDUSTRIES	ALL INDUSTRIES	ALL INDUSTRIES
CONSUMPTION	-9768.8 BILLION BTU	-8886.0 BILLION BTU	-25434.0 BILLION BTU
EXPENDITURES	$ -24318.0 THOUSAND	$ -10533.0 THOUSAND	$ -17839.0 THOUSAND

YEAR	1974	1971	1967
USAGE	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.
USER	CHEMICAL	CHEMICAL	CHEMICAL
CONSUMPTION	73.9 BILLION BTU	51.9 BILLION BTU	147.5 BILLION BTU
EXPENDITURES	$ 0.0 THOUSAND	$ 0.0 THOUSAND	$ 0.0 THOUSAND

YEAR	1974	1971	1967
USAGE	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.
USER	PRIMARY METALS	PRIMARY METALS	PRIMARY METALS
CONSUMPTION	-9842.7 BILLION BTU	-8938.2 BILLION BTU	-25582.0 BILLION BTU
EXPENDITURES	$ -24318.0 THOUSAND	$ -10533.0 THOUSAND	$ -17839.0 THOUSAND

* FUEL=DIST-OIL *

YEAR	1974	1971	1967
USAGE	DIRECT HEAT-TOTAL	DIRECT HEAT-TOTAL	DIRECT HEAT-TOTAL
USER	ALL INDUSTRIES	ALL INDUSTRIES	ALL INDUSTRIES
CONSUMPTION	523.5 BILLION BTU	434.8 BILLION BTU	525.6 BILLION BTU
EXPENDITURES	$ 1131.5 THOUSAND	$ 331.5 THOUSAND	$ 295.2 THOUSAND

YEAR	1974	1971	1967
USAGE	DIRECT HEAT-TOTAL	DIRECT HEAT-TOTAL	DIRECT HEAT-TOTAL
USER	PRIMARY METALS	PRIMARY METALS	PRIMARY METALS
CONSUMPTION	523.5 BILLION BTU	434.8 BILLION BTU	525.6 BILLION BTU
EXPENDITURES	$ 1131.5 THOUSAND	$ 331.5 THOUSAND	$ 295.2 THOUSAND

YEAR	1974	1971	1967
USAGE	DIRECT HEAT-MISC.	DIRECT HEAT-MISC.	DIRECT HEAT-MISC.
USER	ALL INDUSTRIES	ALL INDUSTRIES	ALL INDUSTRIES
CONSUMPTION	523.5 BILLION BTU	434.8 BILLION BTU	525.6 BILLION BTU
EXPENDITURES	$ 1131.5 THOUSAND	$ 331.5 THOUSAND	$ 295.2 THOUSAND

YEAR	1974	1971	1967
USAGE	DIRECT HEAT-MISC.	DIRECT HEAT-MISC.	DIRECT HEAT-MISC.
USER	PRIMARY METALS	PRIMARY METALS	PRIMARY METALS
CONSUMPTION	523.5 BILLION BTU	434.8 BILLION BTU	525.6 BILLION BTU
EXPENDITURES	$ 1131.5 THOUSAND	$ 331.5 THOUSAND	$ 295.2 THOUSAND

YEAR	1974	1971	1967
USAGE	COKE PRODUCTION	COKE PRODUCTION	COKE PRODUCTION
USER	ALL INDUSTRIES	ALL INDUSTRIES	ALL INDUSTRIES
CONSUMPTION	140.6 BILLION BTU	64.6 BILLION BTU	72.4 BILLION BTU
EXPENDITURES	$ 368.5 THOUSAND	$ 48.7 THOUSAND	$ 40.0 THOUSAND

YEAR	1974	1971	1967
USAGE	COKE PRODUCTION	COKE PRODUCTION	COKE PRODUCTION
USER	PRIMARY METALS	PRIMARY METALS	PRIMARY METALS
CONSUMPTION	140.6 BILLION BTU	64.6 BILLION BTU	72.4 BILLION BTU
EXPENDITURES	$ 368.5 THOUSAND	$ 48.7 THOUSAND	$ 40.0 THOUSAND

* FUEL=DIST-OIL *

YEAR	1974	1971	1967
USAGE	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.
USER	ALL INDUSTRIES	ALL INDUSTRIES	ALL INDUSTRIES
CONSUMPTION	3035.0 BILLION BTU	2609.0 BILLION BTU	1975.4 BILLION BTU
EXPENDITURES	$ 6290.5 THOUSAND	$ 1948.4 THOUSAND	$ 1222.8 THOUSAND
YEAR	1974	1971	1967
USAGE	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.
USER	CHEMICAL	CHEMICAL	CHEMICAL
CONSUMPTION	638.6 BILLION BTU	434.9 BILLION BTU	238.1 BILLION BTU
EXPENDITURES	$ 1300.3 THOUSAND	$ 300.0 THOUSAND	$ 127.4 THOUSAND
YEAR	1974	1971	1967
USAGE	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.
USER	STONE, ETC.	STONE, ETC.	STONE, ETC.
CONSUMPTION	0.0 BILLION BTU	125.2 BILLION BTU	65.1 BILLION BTU
EXPENDITURES	$ 0.0 THOUSAND	$ 94.2 THOUSAND	$ 49.8 THOUSAND
YEAR	1974	1971	1967
USAGE	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.
USER	PRIMARY METALS	PRIMARY METALS	PRIMARY METALS
CONSUMPTION	384.6 BILLION BTU	792.7 BILLION BTU	838.5 BILLION BTU
EXPENDITURES	$ 1926.4 THOUSAND	$ 609.9 THOUSAND	$ 471.7 THOUSAND

FUEL=RESID-OIL

YEAR	1974	1971	1967
USAGE	DIRECT HEAT-TOTAL	DIRECT HEAT-TOTAL	DIRECT HEAT-TOTAL
USER	ALL INDUSTRIES	ALL INDUSTRIES	ALL INDUSTRIES
CONSUMPTION	6798.5 BILLION BTU	5063.0 BILLION BTU	6252.1 BILLION BTU
EXPENDITURES	$ 17578.5 THOUSAND	$ 3316.3 THOUSAND	$ 3233.3 THOUSAND

YEAR	1974	1971	1967
USAGE	DIRECT HEAT-TOTAL	DIRECT HEAT-TOTAL	DIRECT HEAT-TOTAL
USER	PRIMARY METALS	PRIMARY METALS	PRIMARY METALS
CONSUMPTION	6798.5 BILLION BTU	5063.0 BILLION BTU	6252.1 BILLION BTU
EXPENDITURES	$ 17578.5 THOUSAND	$ 3316.3 THOUSAND	$ 3233.3 THOUSAND

YEAR	1974	1971	1967
USAGE	DIRECT HEAT-MISC.	DIRECT HEAT-MISC.	DIRECT HEAT-MISC.
USER	ALL INDUSTRIES	ALL INDUSTRIES	ALL INDUSTRIES
CONSUMPTION	6798.5 BILLION BTU	5063.0 BILLION BTU	6252.1 BILLION BTU
EXPENDITURES	$ 17578.5 THOUSAND	$ 3316.3 THOUSAND	$ 3233.3 THOUSAND

YEAR	1974	1971	1967
USAGE	DIRECT HEAT-MISC.	DIRECT HEAT-MISC.	DIRECT HEAT-MISC.
USER	PRIMARY METALS	PRIMARY METALS	PRIMARY METALS
CONSUMPTION	6798.5 BILLION BTU	5063.0 BILLION BTU	6252.1 BILLION BTU
EXPENDITURES	$ 17578.5 THOUSAND	$ 3316.3 THOUSAND	$ 3233.3 THOUSAND

YEAR	1974	1971	1967
USAGE	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.
USER	ALL INDUSTRIES	ALL INDUSTRIES	ALL INDUSTRIES
CONSUMPTION	16863.2 BILLION BTU	7926.2 BILLION BTU	8589.6 BILLION BTU
EXPENDITURES	$ 34091.6 THOUSAND	$ 5429.1 THOUSAND	$ 4475.0 THOUSAND

YEAR	1974	1971	1967
USAGE	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.
USER	CHEMICAL	CHEMICAL	CHEMICAL
CONSUMPTION	2346.7 BILLION BTU	225.8 BILLION BTU	147.6 BILLION BTU
EXPENDITURES	$ 4500.0 THOUSAND	$ 203.0 THOUSAND	$ 82.0 THOUSAND

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* FUEL=RESID-OIL*
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YEAR	1974	1971	1967
USAGE	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.
USER	STONE, ETC.	STONE, ETC.	STONE, ETC.
CONSUMPTION	0.0 BILLION BTU	94.9 BILLION BTU	70.5 BILLION BTU
EXPENDITURES	$ 0.0 THOUSAND	$ 60.7 THOUSAND	$ 37.2 THOUSAND

YEAR	1974	1971	1967
USAGE	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.
USER	PRIMARY METALS	PRIMARY METALS	PRIMARY METALS
CONSUMPTION	10581.2 BILLION BTU	6618.0 BILLION BTU	7478.9 BILLION BTU
EXPENDITURES	$ 21500.1 THOUSAND	$ 4333.5 THOUSAND	$ 3860.9 THOUSAND

* FUEL=LPG *

YEAR	1974	1971	1967
USAGE	DIRECT HEAT-TOTAL	DIRECT HEAT-TOTAL	DIRECT HEAT-TOTAL
USER	ALL INDUSTRIES	ALL INDUSTRIES	ALL INDUSTRIES
CONSUMPTION	112.2 BILLION BTU	126.9 BILLION BTU	163.4 BILLION BTU
EXPENDITURES	$ 0.0 THOUSAND	$ 0.0 THOUSAND	$ 0.0 THOUSAND

YEAR	1974	1971	1967
USAGE	DIRECT HEAT-TOTAL	DIRECT HEAT-TOTAL	DIRECT HEAT-TOTAL
USER	PRIMARY METALS	PRIMARY METALS	PRIMARY METALS
CONSUMPTION	112.2 BILLION BTU	126.9 BILLION BTU	163.4 BILLION BTU
EXPENDITURES	$ 0.0 THOUSAND	$ 0.0 THOUSAND	$ 0.0 THOUSAND

YEAR	1974	1971	1967
USAGE	DIRECT HEAT-MISC.	DIRECT HEAT-MISC.	DIRECT HEAT-MISC.
USER	ALL INDUSTRIES	ALL INDUSTRIES	ALL INDUSTRIES
CONSUMPTION	112.2 BILLION BTU	126.9 BILLION BTU	163.4 BILLION BTU
EXPENDITURES	$ 0.0 THOUSAND	$ 0.0 THOUSAND	$ 0.0 THOUSAND

YEAR	1974	1971	1967
USAGE	DIRECT HEAT-MISC.	DIRECT HEAT-MISC.	DIRECT HEAT-MISC.
USER	PRIMARY METALS	PRIMARY METALS	PRIMARY METALS
CONSUMPTION	112.2 BILLION BTU	126.9 BILLION BTU	163.4 BILLION BTU
EXPENDITURES	$ 0.0 THOUSAND	$ 0.0 THOUSAND	$ 0.0 THOUSAND

YEAR	1974	1971	1967
USAGE	RAW MATERIAL PROD.	RAW MATERIAL PROD.	RAW MATERIAL PROD.
USER	ALL INDUSTRIES	ALL INDUSTRIES	ALL INDUSTRIES
CONSUMPTION	1756.0 BILLION BTU	31981.3 BILLION BTU	44753.1 BILLION BTU
EXPENDITURES	$ 0.0 THOUSAND	$ 0.0 THOUSAND	$ 0.0 THOUSAND

YEAR	1974	1971	1967
USAGE	RAW MATERIAL PROD.	RAW MATERIAL PROD.	RAW MATERIAL PROD.
USER	CHEMICAL	CHEMICAL	CHEMICAL
CONSUMPTION	1756.0 BILLION BTU	31981.3 BILLION BTU	44753.1 BILLION BTU
EXPENDITURES	$ 0.0 THOUSAND	$ 0.0 THOUSAND	$ 0.0 THOUSAND

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* FUEL=LPG *
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YEAR	1974	1971	1967
USAGE	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.
USER	ALL INDUSTRIES	ALL INDUSTRIES	ALL INDUSTRIES
CONSUMPTION	1956.8 BILLION BTU	32212.3 BILLION BTU	44988.2 BILLION BTU
EXPENDITURES	$ 0.0 THOUSAND	$ 0.0 THOUSAND	$ 0.0 THOUSAND

YEAR	1974	1971	1967
USAGE	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.
USER	CHEMICAL	CHEMICAL	CHEMICAL
CONSUMPTION	1756.0 BILLION BTU	31961.3 BILLION BTU	44753.1 BILLION BTU
EXPENDITURES	$ 0.0 THOUSAND	$ 0.0 THOUSAND	$ 0.0 THOUSAND

YEAR	1974	1971	1967
USAGE	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.
USER	PRIMARY METALS	PRIMARY METALS	PRIMARY METALS
CONSUMPTION	202.5 BILLION BTU	231.0 BILLION BTU	235.1 BILLION BTU
EXPENDITURES	$ 0.0 THOUSAND	$ 0.0 THOUSAND	$ 0.0 THOUSAND

MANUFACTURING SECTOR WEST VIRGINIA

* FUEL=NAT-GAS *

YEAR	1974	1971	1967
USAGE	DIRECT HEAT-TOTAL	DIRECT HEAT-TOTAL	DIRECT HEAT-TOTAL
USER	ALL INDUSTRIES	ALL INDUSTRIES	ALL INDUSTRIES
CONSUMPTION	9051.1 BILLION BTU	8832.6 BILLION BTU	9406.0 BILLION BTU
EXPENDITURES	$ 6775.5 THOUSAND	$ 3753.7 THOUSAND	$ 3051.4 THOUSAND

YEAR	1974	1971	1967
USAGE	DIRECT HEAT-TOTAL	DIRECT HEAT-TOTAL	DIRECT HEAT-TOTAL
USER	PRIMARY METALS	PRIMARY METALS	PRIMARY METALS
CONSUMPTION	9051.1 BILLION BTU	8832.6 BILLION BTU	9406.0 BILLION BTU
EXPENDITURES	$ 6775.5 THOUSAND	$ 3753.7 THOUSAND	$ 3051.4 THOUSAND

YEAR	1974	1971	1967
USAGE	DIRECT HEAT-MISC.	DIRECT HEAT-MISC.	DIRECT HEAT-MISC.
USER	ALL INDUSTRIES	ALL INDUSTRIES	ALL INDUSTRIES
CONSUMPTION	9051.1 BILLION BTU	8832.6 BILLION BTU	9406.0 BILLION BTU
EXPENDITURES	$ 6775.5 THOUSAND	$ 3753.7 THOUSAND	$ 3051.4 THOUSAND

YEAR	1974	1971	1967
USAGE	DIRECT HEAT-MISC.	DIRECT HEAT-MISC.	DIRECT HEAT-MISC.
USER	PRIMARY METALS	PRIMARY METALS	PRIMARY METALS
CONSUMPTION	9051.1 BILLION BTU	8832.6 BILLION BTU	9406.0 BILLION BTU
EXPENDITURES	$ 6775.5 THOUSAND	$ 3753.7 THOUSAND	$ 3051.4 THOUSAND

YEAR	1974	1971	1967
USAGE	RAW MATERIAL PROD.	RAW MATERIAL PROD.	RAW MATERIAL PROD.
USER	ALL INDUSTRIES	ALL INDUSTRIES	ALL INDUSTRIES
CONSUMPTION	10991.9 BILLION BTU	10682.0 BILLION BTU	13178.6 BILLION BTU
EXPENDITURES	$ 8164.4 THOUSAND	$ 5313.2 THOUSAND	$ 5225.9 THOUSAND

YEAR	1974	1971	1967
USAGE	RAW MATERIAL PROD.	RAW MATERIAL PROD.	RAW MATERIAL PROD.
USER	CHEMICAL	CHEMICAL	CHEMICAL
CONSUMPTION	10991.9 BILLION BTU	10682.0 BILLION BTU	13178.6 BILLION BTU
EXPENDITURES	$ 8164.4 THOUSAND	$ 5313.2 THOUSAND	$ 5225.9 THOUSAND

FUEL=NAT-GAS

YEAR	1974	1971	1967
USAGE	COKE PRODUCTION	COKE PRODUCTION	COKE PRODUCTION
USER	ALL INDUSTRIES	ALL INDUSTRIES	ALL INDUSTRIES
CONSUMPTION	12.5 BILLION BTU	18.0 BILLION BTU	13.6 BILLION BTU
EXPENDITURES	$ 10.0 THOUSAND	$ 9.1 THOUSAND	$ 5.0 THOUSAND

YEAR	1974	1971	1967
USAGE	COKE PRODUCTION	COKE PRODUCTION	COKE PRODUCTION
USER	PRIMARY METALS	PRIMARY METALS	PRIMARY METALS
CONSUMPTION	12.5 BILLION BTU	18.0 BILLION BTU	13.6 BILLION BTU
EXPENDITURES	$ 10.0 THOUSAND	$ 9.1 THOUSAND	$ 5.0 THOUSAND

YEAR	1974	1971	1967
USAGE	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.
USER	ALL INDUSTRIES	ALL INDUSTRIES	ALL INDUSTRIES
CONSUMPTION	83659.5 BILLION BTU	77522.8 BILLION BTU	71155.2 BILLION BTU
EXPENDITURES	$ 62276.3 THOUSAND	$ 38510.6 THOUSAND	$ 29082.0 THOUSAND

YEAR	1974	1971	1967
USAGE	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.
USER	CHEMICAL	CHEMICAL	CHEMICAL
CONSUMPTION	38456.8 BILLION BTU	30786.5 BILLION BTU	30156.0 BILLION BTU
EXPENDITURES	$ 28564.3 THOUSAND	$ 15313.2 THOUSAND	$ 11958.1 THOUSAND

YEAR	1974	1971	1967
USAGE	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.
USER	STONE, ETC.	STONE, ETC.	STONE, ETC.
CONSUMPTION	21950.3 BILLION BTU	25775.0 BILLION BTU	22863.3 BILLION BTU
EXPENDITURES	$ 16100.0 THOUSAND	$ 13200.0 THOUSAND	$ 10058.1 THOUSAND

YEAR	1974	1971	1967
USAGE	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.
USER	PRIMARY METALS	PRIMARY METALS	PRIMARY METALS
CONSUMPTION	15832.6 BILLION BTU	14612.1 BILLION BTU	14005.8 BILLION BTU
EXPENDITURES	$ 11416.7 THOUSAND	$ 6699.3 THOUSAND	$ 5075.3 THOUSAND

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MANUFACTURING SECTOR WEST VIRGINIA
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* FUEL=ELECTRIC *
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YEAR	1974	1971	1967
USAGE	DIRECT HEAT-TOTAL	DIRECT HEAT-TOTAL	DIRECT HEAT-TOTAL
USER	ALL INDUSTRIES	ALL INDUSTRIES	ALL INDUSTRIES
CONSUMPTION	1769.1 BILLION BTU	1323.0 BILLION BTU	1055.4 BILLION BTU
EXPENDITURES	$ 6661.0 THOUSAND	$ 2356.1 THOUSAND	$ 2111.7 THOUSAND

YEAR	1974	1971	1967
USAGE	DIRECT HEAT-TOTAL	DIRECT HEAT-TOTAL	DIRECT HEAT-TOTAL
USER	PRIMARY METALS	PRIMARY METALS	PRIMARY METALS
CONSUMPTION	1769.1 BILLION BTU	1323.0 BILLION BTU	1055.4 BILLION BTU
EXPENDITURES	$ 6681.0 THOUSAND	$ 2356.1 THOUSAND	$ 2111.7 THOUSAND

YEAR	1974	1971	1967
USAGE	DIRECT HEAT-MISC.	DIRECT HEAT-MISC.	DIRECT HEAT-MISC.
USER	ALL INDUSTRIES	ALL INDUSTRIES	ALL INDUSTRIES
CONSUMPTION	1769.1 BILLION BTU	1323.0 BILLION BTU	1055.4 BILLION BTU
EXPENDITURES	$ 6661.0 THOUSAND	$ 2356.1 THOUSAND	$ 2111.7 THOUSAND

YEAR	1974	1971	1967
USAGE	DIRECT HEAT-MISC.	DIRECT HEAT-MISC.	DIRECT HEAT-MISC.
USER	PRIMARY METALS	PRIMARY METALS	PRIMARY METALS
CONSUMPTION	1769.1 BILLION BTU	1323.0 BILLION BTU	1055.4 BILLION BTU
EXPENDITURES	$ 6661.0 THOUSAND	$ 2356.1 THOUSAND	$ 2111.7 THOUSAND

YEAR	1974	1971	1967
USAGE	ELECTRIC GERATION	ELECTRIC GERATION	ELECTRIC GERATION
USER	ALL INDUSTRIES	ALL INDUSTRIES	ALL INDUSTRIES
CONSUMPTION	-2154.5 BILLION BTU	-2255.0 BILLION BTU	-2414.6 BILLION BTU
EXPENDITURES	$ -8947.4 THOUSAND	$ -4189.9 THOUSAND	$ -5572.1 THOUSAND

YEAR	1974	1971	1967
USAGE	ELECTRIC GERATION	ELECTRIC GERATION	ELECTRIC GERATION
USER	PRIMARY METALS	PRIMARY METALS	PRIMARY METALS
CONSUMPTION	-2154.5 BILLION BTU	-2255.0 BILLION BTU	-2414.6 BILLION BTU
EXPENDITURES	$ -8947.4 THOUSAND	$ -4189.9 THOUSAND	$ -5572.1 THOUSAND

* FUEL=ELECTRIC *

YEAR	1974	1971	1967
USAGE	COKE PRODUCTION	COKE PRODUCTION	COKE PRODUCTION
USER	ALL INDUSTRIES	ALL INDUSTRIES	ALL INDUSTRIES
CONSUMPTION	208.2 BILLION BTU	189.9 BILLION BTU	215.3 BILLION BTU
EXPENDITURES	$ 560.6 THOUSAND	$ 352.9 THOUSAND	$ 496.8 THOUSAND

YEAR	1974	1971	1967
USAGE	COKE PRODUCTION	COKE PRODUCTION	COKE PRODUCTION
USER	PRIMARY METALS	PRIMARY METALS	PRIMARY METALS
CONSUMPTION	208.2 BILLION BTU	189.9 BILLION BTU	215.3 BILLION BTU
EXPENDITURES	$ 560.6 THOUSAND	$ 352.9 THOUSAND	$ 496.8 THOUSAND

YEAR	1974	1971	1967
USAGE	MACHINE DRIVE	MACHINE DRIVE	MACHINE DRIVE
USER	ALL INDUSTRIES	ALL INDUSTRIES	ALL INDUSTRIES
CONSUMPTION	645.5 BILLION BTU	544.3 BILLION BTU	636.5 BILLION BTU
EXPENDITURES	$ 1218.5 THOUSAND	$ 776.9 THOUSAND	$ 725.7 THOUSAND

YEAR	1974	1971	1967
USAGE	MACHINE DRIVE	MACHINE DRIVE	MACHINE DRIVE
USER	PRIMARY METALS	PRIMARY METALS	PRIMARY METALS
CONSUMPTION	645.5 BILLION BTU	544.3 BILLION BTU	636.5 BILLION BTU
EXPENDITURES	$ 1218.5 THOUSAND	$ 776.9 THOUSAND	$ 725.7 THOUSAND

YEAR	1974	1971	1967
USAGE	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.
USER	ALL INDUSTRIES	ALL INDUSTRIES	ALL INDUSTRIES
CONSUMPTION	40076.3 BILLION BTU	35255.3 BILLION BTU	33868.1 BILLION BTU
EXPENDITURES	$ 134049.0 THOUSAND	$ 71589.0 THOUSAND	$ 56752.7 THOUSAND

YEAR	1974	1971	1967
USAGE	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.
USER	CHEMICAL	CHEMICAL	CHEMICAL
CONSUMPTION	13183.4 BILLION BTU	13752.7 BILLION BTU	13170.2 BILLION BTU
EXPENDITURES	$ 43099.4 THOUSAND	$ 28699.9 THOUSAND	$ 21725.5 THOUSAND

FUEL=ELECTRIC

YEAR	1974	1971	1967
USAGE	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.
USER	STONE, ETC.	STONE, ETC.	STONE, ETC.
CONSUMPTION	2669.1 BILLION BTU	1851.0 BILLION BTU	1462.2 BILLION BTU
EXPENDITURES	$ 7900.0 THOUSAND	$ 5400.0 THOUSAND	$ 4129.9 THOUSAND

YEAR	1974	1971	1967
USAGE	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.
USER	PRIMARY METALS	PRIMARY METALS	PRIMARY METALS
CONSUMPTION	26035.2 BILLION BTU	16141.4 BILLION BTU	16683.8 BILLION BTU
EXPENDITURES	$ 56364.7 THOUSAND	$ 27479.5 THOUSAND	$ 23739.8 THOUSAND

* FUEL=TOTAL *

YEAR	1974	1971	1967
USAGE	DIRECT HEAT-TOTAL	DIRECT HEAT-TOTAL	DIRECT HEAT-TOTAL
USER	ALL INDUSTRIES	ALL INDUSTRIES	ALL INDUSTRIES
CONSUMPTION	39986.1 BILLION BTU	30947.4 BILLION BTU	34002.1 BILLION BTU
EXPENDITURES	$ 53132.6 THOUSAND	$ 17688.5 THOUSAND	$ 15863.7 THOUSAND

YEAR	1974	1971	1967
USAGE	DIRECT HEAT-TOTAL	DIRECT HEAT-TOTAL	DIRECT HEAT-TOTAL
USER	PRIMARY METALS	PRIMARY METALS	PRIMARY METALS
CONSUMPTION	39986.1 BILLION BTU	30947.4 BILLION BTU	34002.1 BILLION BTU
EXPENDITURES	$ 53132.6 THOUSAND	$ 17688.5 THOUSAND	$ 15863.7 THOUSAND

YEAR	1974	1971	1967
USAGE	DIRECT HEAT-MISC.	DIRECT HEAT-MISC.	DIRECT HEAT-MISC.
USER	ALL INDUSTRIES	ALL INDUSTRIES	ALL INDUSTRIES
CONSUMPTION	39986.1 BILLION BTU	30947.4 BILLION BTU	34002.1 BILLION BTU
EXPENDITURES	$ 53132.6 THOUSAND	$ 17688.5 THOUSAND	$ 15863.7 THOUSAND

YEAR	1974	1971	1967
USAGE	DIRECT HEAT-MISC.	DIRECT HEAT-MISC.	DIRECT HEAT-MISC.
USER	PRIMARY METALS	PRIMARY METALS	PRIMARY METALS
CONSUMPTION	39986.1 BILLION BTU	30947.4 BILLION BTU	34002.1 BILLION BTU
EXPENDITURES	$ 53132.6 THOUSAND	$ 17688.5 THOUSAND	$ 15863.7 THOUSAND

YEAR	1974	1971	1967
USAGE	RAW MATERIAL PROD.	RAW MATERIAL PROD.	RAW MATERIAL PROD.
USER	ALL INDUSTRIES	ALL INDUSTRIES	ALL INDUSTRIES
CONSUMPTION	132093.0 BILLION BTU	131893.0 BILLION BTU	152007.0 BILLION BTU
EXPENDITURES	$ 245567.0 THOUSAND	$ 85612.6 THOUSAND	$ 55508.2 THOUSAND

YEAR	1974	1971	1967
USAGE	RAW MATERIAL PROD.	RAW MATERIAL PROD.	RAW MATERIAL PROD.
USER	CHEMICAL	CHEMICAL	CHEMICAL
CONSUMPTION	44292.0 BILLION BTU	65380.2 BILLION BTU	81190.6 BILLION BTU
EXPENDITURES	$ 6164.4 THOUSAND	$ 5513.2 THOUSAND	$ 5225.9 THOUSAND

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* FUEL=TOTAL *

YEAR	1974	1971	1967
USAGE	RAW MATERIAL PROD.	RAW MATERIAL PROD.	RAW MATERIAL PROD.
USER	PRIMARY METALS	PRIMARY METALS	PRIMARY METALS
CONSUMPTION	826[illegible].5 BILLION BTU	66512.5 BILLION BTU	70815.4 BILLION BTU
EXPENDITURES	$ 23772[illegible] THOUSAND	$ 80299.4 THOUSAND	$ 58282.4 THOUSAND

YEAR	1974	1971	1967
USAGE	STEAM PRODUCTION	STEAM PRODUCTION	STEAM PRODUCTION
USER	ALL INDUSTRIES	ALL INDUSTRIES	ALL INDUSTRIES
CONSUMPTION	5235.0 BILLION BTU	2095.0 BILLION BTU	4532.4 BILLION BTU
EXPENDITURES	$ 4612.8 THOUSAND	$ 741.2 THOUSAND	$ 1448.0 THOUSAND

YEAR	1974	1971	1967
USAGE	STEAM PRODUCTION	STEAM PRODUCTION	STEAM PRODUCTION
USER	PRIMARY METALS	PRIMARY METALS	PRIMARY METALS
CONSUMPTION	5235.0 BILLION BTU	2095.0 BILLION BTU	4532.4 BILLION BTU
EXPENDITURES	$ 4612.8 THOUSAND	$ 741.2 THOUSAND	$ 1448.0 THOUSAND

YEAR	1974	1971	1967
USAGE	ELECTRIC GERATION	ELECTRIC GERATION	ELECTRIC GERATION
USER	ALL INDUSTRIES	ALL INDUSTRIES	ALL INDUSTRIES
CONSUMPTION	5262.5 BILLION BTU	4856.0 BILLION BTU	5187.2 BILLION BTU
EXPENDITURES	$ -2403.3 THOUSAND	$ -1675.6 THOUSAND	$ -3144.6 THOUSAND

YEAR	1974	1971	1967
USAGE	ELECTRIC GERATION	ELECTRIC GERATION	ELECTRIC GERATION
USER	PRIMARY METALS	PRIMARY METALS	PRIMARY METALS
CONSUMPTION	5262.5 BILLION BTU	4856.0 BILLION BTU	5187.2 BILLION BTU
EXPENDITURES	$ -2403.3 THOUSAND	$ -1675.6 THOUSAND	$ -3144.6 THOUSAND

YEAR	1974	1971	1967
USAGE	COKE PRODUCTION	COKE PRODUCTION	COKE PRODUCTION
USER	ALL INDUSTRIES	ALL INDUSTRIES	ALL INDUSTRIES
CONSUMPTION	19441.7 BILLION BTU	17738.6 BILLION BTU	23909.4 BILLION BTU
EXPENDITURES	$ -132360.0 THOUSAND	$ -48719.0 THOUSAND	$ -37247.0 THOUSAND

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* FUEL=TOTAL *
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YEAR	1974	1971	1967
USAGE	COKE PRODUCTION	COKE PRODUCTION	COKE PRODUCTION
USER	PRIMARY METALS	PRIMARY METALS	PRIMARY METALS
CONSUMPTION	19441.7 BILLION BTU	17738.6 BILLION BTU	23909.4 BILLION BTU
EXPENDITURES	$ -132360.0 THOUSAND	$ -48719.0 THOUSAND	$ -37247.0 THOUSAND

YEAR	1974	1971	1967
USAGE	MACHINE DRIVE	MACHINE DRIVE	MACHINE DRIVE
USER	ALL INDUSTRIES	ALL INDUSTRIES	ALL INDUSTRIES
CONSUMPTION	645.5 BILLION BTU	544.3 BILLION BTU	636.5 BILLION BTU
EXPENDITURES	$ 1218.5 THOUSAND	$ 776.9 THOUSAND	$ 725.7 THOUSAND

YEAR	1974	1971	1967
USAGE	MACHINE DRIVE	MACHINE DRIVE	MACHINE DRIVE
USER	PRIMARY METALS	PRIMARY METALS	PRIMARY METALS
CONSUMPTION	645.5 BILLION BTU	544.3 BILLION BTU	636.5 BILLION BTU
EXPENDITURES	$ 1218.5 THOUSAND	$ 776.9 THOUSAND	$ 725.7 THOUSAND

YEAR	1974	1971	1967
USAGE	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.
USER	ALL INDUSTRIES	ALL INDUSTRIES	ALL INDUSTRIES
CONSUMPTION	397590.0 BILLION BTU	380972.0 BILLION BTU	424096.0 BILLION BTU
EXPENDITURES	$ 435409.0 THOUSAND	$ 197958.0 THOUSAND	$ 144300.0 THOUSAND

YEAR	1974	1971	1967
USAGE	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.
USER	CHEMICAL	CHEMICAL	CHEMICAL
CONSUMPTION	153931.0 BILLION BTU	179911.0 BILLION BTU	207419.0 BILLION BTU
EXPENDITURES	$ 131364.0 THOUSAND	$ 74413.0 THOUSAND	$ 55957.9 THOUSAND

YEAR	1974	1971	1967
USAGE	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.
USER	STONE, ETC.	STONE, ETC.	STONE, ETC.
CONSUMPTION	31676.5 BILLION BTU	34670.6 BILLION BTU	31997.8 BILLION BTU
EXPENDITURES	$ 31199.9 THOUSAND	$ 22354.8 THOUSAND	$ 17095.8 THOUSAND

* FUEL=TOTAL *

YEAR	1974	1971	1967
USAGE	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.
USER	PRIMARY METALS	PRIMARY METALS	PRIMARY METALS
CONSUMPTION	185320.0 BILLION BTU	150208.0 BILLION BTU	169550.0 BILLION BTU
EXPENDITURES	$ 232057.0 THOUSAND	$ 34367.2 THOUSAND	$ 58684.3 THOUSAND

FUEL=MO-GAS

YEAR	1974	1971	1967
USAGE	PASS-LOCAL-TOTAL	PASS-LOCAL-TOTAL	PASS-LOCAL-TOTAL
USER	ALL TRANSPORTATION	ALL TRANSPORTATION	ALL TRANSPORTATION
CONSUMPTION	79757.8 BILLION BTU	72322.4 BILLION BTU	58459.8 BILLION BTU
EXPENDITURES	$ 0.0 THOUSAND	$ 0.0 THOUSAND	$ 0.0 THOUSAND

YEAR	1974	1971	1967
USAGE	PASS-LOCAL-TOTAL	PASS-LOCAL-TOTAL	PASS-LOCAL-TOTAL
USER	TRUCKING-TOTAL	TRUCKING-TOTAL	TRUCKING-TOTAL
CONSUMPTION	11561.6 BILLION BTU	10037.4 BILLION BTU	8031.5 BILLION BTU
EXPENDITURES	$ 0.0 THOUSAND	$ 0.0 THOUSAND	$ 0.0 THOUSAND

YEAR	1974	1971	1967
USAGE	PASS-LOCAL-TOTAL	PASS-LOCAL-TOTAL	PASS-LOCAL-TOTAL
USER	CAR-ALL	CAR-ALL	CAR-ALL
CONSUMPTION	67375.7 BILLION BTU	61540.3 BILLION BTU	49756.6 BILLION BTU
EXPENDITURES	$ 0.0 THOUSAND	$ 0.0 THOUSAND	$ 0.0 THOUSAND

YEAR	1974	1971	1967
USAGE	PASS-LOCAL-TOTAL	PASS-LOCAL-TOTAL	PASS-LOCAL-TOTAL
USER	CAR-PRIVATE	CAR-PRIVATE	CAR-PRIVATE
CONSUMPTION	67375.7 BILLION BTU	61540.3 BILLION BTU	49756.6 BILLION BTU
EXPENDITURES	$ 0.0 THOUSAND	$ 0.0 THOUSAND	$ 0.0 THOUSAND

YEAR	1974	1971	1967
USAGE	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.
USER	ALL TRANSPORTATION	ALL TRANSPORTATION	ALL TRANSPORTATION
CONSUMPTION	107865.0 BILLION BTU	96623.3 BILLION BTU	77950.5 BILLION BTU
EXPENDITURES	$ 0.0 THOUSAND	$ 0.0 THOUSAND	$ 0.0 THOUSAND

YEAR	1974	1971	1967
USAGE	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.
USER	TRUCKING-TOTAL	TRUCKING-TOTAL	TRUCKING-TOTAL
CONSUMPTION	34455.4 BILLION BTU	29865.3 BILLION BTU	23896.9 BILLION BTU
EXPENDITURES	$ 0.0 THOUSAND	$ 0.0 THOUSAND	$ 0.0 THOUSAND

* FUEL=MO-GAS *

YEAR	1974	1971	1967
USAGE	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.
USER	CAR-ALL	CAR-ALL	CAR-ALL
CONSUMPTION	71629.6 BILLION BTU	65989.5 BILLION BTU	53354.0 BILLION BTU
EXPENDITURES	$ 0.0 THOUSAND	$ 0.0 THOUSAND	$ 0.0 THOUSAND

YEAR	1974	1971	1967
USAGE	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.
USER	CAR-PRIVATE	CAR-PRIVATE	CAR-PRIVATE
CONSUMPTION	71629.6 BILLION BTU	65989.5 BILLION BTU	53354.0 BILLION BTU
EXPENDITURES	$ 0.0 THOUSAND	$ 0.0 THOUSAND	$ 0.0 THOUSAND

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* FUEL=DIST-OIL *
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YEAR	1974	1971	1967
USAGE	PASS-LOCAL-TOTAL	PASS-LOCAL-TOTAL	PASS-LOCAL-TOTAL
USER	ALL TRANSPORTATION	ALL TRANSPORTATION	ALL TRANSPORTATION
CONSUMPTION	351.3 BILLION BTU	419.6 BILLION BTU	379.6 BILLION BTU
EXPENDITURES	$ 0.0 THOUSAND	$ 0.0 THOUSAND	$ 0.0 THOUSAND

YEAR	1974	1971	1967
USAGE	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.
USER	ALL TRANSPORTATION	ALL TRANSPORTATION	ALL TRANSPORTATION
CONSUMPTION	22082.4 BILLION BTU	15428.3 BILLION BTU	13095.5 BILLION BTU
EXPENDITURES	$ 0.0 THOUSAND	$ 0.0 THOUSAND	$ 0.0 THOUSAND

YEAR	1974	1971	1967
USAGE	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.
USER	TRUCKING-TOTAL	TRUCKING-TOTAL	TRUCKING-TOTAL
CONSUMPTION	12077.6 BILLION BTU	10485.4 BILLION BTU	8390.0 BILLION BTU
EXPENDITURES	$ 0.0 THOUSAND	$ 0.0 THOUSAND	$ 0.0 THOUSAND

* FUEL=RESID-OIL*

YEAR	1974	1971	1967
USAGE	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.
USER	ALL TRANSPORTATION	ALL TRANSPORTATION	ALL TRANSPORTATION
CONSUMPTION	2329.5 BILLION BTU	0.0 BILLION BTU	475.5 BILLION BTU
EXPENDITURES	$ 0.0 THOUSAND	$ 0.0 THOUSAND	$ 0.0 THOUSAND

****
* FUEL=NAT-GAS *
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YEAR	1974	1971	1967
USAGE	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.
USER	ALL TRANSPORTATION	ALL TRANSPORTATION	ALL TRANSPORTATION
CONSUMPTION	16644.6 BILLION BTU	10375.8 BILLION BTU	17244.6 BILLION BTU
EXPENDITURES	$ 0.0 THOUSAND	$ 0.0 THOUSAND	$ 0.0 THOUSAND

****
* FUEL=ELECTRIC *
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YEAR	1974	1971	1967
USAGE	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.
USER	ALL TRANSPORTATION	ALL TRANSPORTATION	ALL TRANSPORTATION
CONSUMPTION	53.2 BILLION BTU	48.9 BILLION BTU	51.5 BILLION BTU
EXPENDITURES	$ 0.0 THOUSAND	$ 0.0 THOUSAND	$ 0.0 THOUSAND

* FUEL=TOTAL *

YEAR	1974	1971	1967
USAGE	PASS-LOCAL-TOTAL	PASS-LOCAL-TOTAL	PASS-LOCAL-TOTAL
USER	ALL TRANSPORTATION	ALL TRANSPORTATION	ALL TRANSPORTATION
CONSUMPTION	80136.5 BILLION BTU	72773.7 BILLION BTU	58876.0 BILLION BTU
EXPENDITURES	$ 0.0 THOUSAND	$ 0.0 THOUSAND	$ 0.0 THOUSAND

YEAR	1974	1971	1967
USAGE	PASS-LOCAL-TOTAL	PASS-LOCAL-TOTAL	PASS-LOCAL-TOTAL
USER	TRUCKING-TOTAL	TRUCKING-TOTAL	TRUCKING-TOTAL
CONSUMPTION	11551.6 BILLION BTU	10037.4 BILLION BTU	8031.5 BILLION BTU
EXPENDITURES	$ 0.0 THOUSAND	$ 0.0 THOUSAND	$ 0.0 THOUSAND

YEAR	1974	1971	1967
USAGE	PASS-LOCAL-TOTAL	PASS-LOCAL-TOTAL	PASS-LOCAL-TOTAL
USER	CAR-ALL	CAR-ALL	CAR-ALL
CONSUMPTION	67375.7 BILLION BTU	61540.3 BILLION BTU	49756.6 BILLION BTU
EXPENDITURES	$ 0.0 THOUSAND	$ 0.0 THOUSAND	$ 0.0 THOUSAND

YEAR	1974	1971	1967
USAGE	PASS-LOCAL-TOTAL	PASS-LOCAL-TOTAL	PASS-LOCAL-TOTAL
USER	CAR-PRIVATE	CAR-PRIVATE	CAR-PRIVATE
CONSUMPTION	67375.7 BILLION BTU	61540.3 BILLION BTU	49756.6 BILLION BTU
EXPENDITURES	$ 0.0 THOUSAND	$ 0.0 THOUSAND	$ 0.0 THOUSAND

YEAR	1974	1971	1967
USAGE	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.
USER	ALL TRANSPORTATION	ALL TRANSPORTATION	ALL TRANSPORTATION
CONSUMPTION	146570.0 BILLION BTU	123469.0 BILLION BTU	109817.0 BILLION BTU
EXPENDITURES	$ 0.0 THOUSAND	$ 0.0 THOUSAND	$ 0.0 THOUSAND

YEAR	1974	1971	1967
USAGE	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.
USER	TRUCKING-TOTAL	TRUCKING-TOTAL	TRUCKING-TOTAL
CONSUMPTION	45473.1 BILLION BTU	40350.8 BILLION BTU	32286.8 BILLION BTU
EXPENDITURES	$ 0.0 THOUSAND	$ 0.0 THOUSAND	$ 0.0 THOUSAND

* FUEL=TOTAL *

YEAR	1974	1971	1967
USAGE	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.
USER	CAR-ALL	CAR-ALL	CAR-ALL
CONSUMPTION	71329.6 BILLION BTU	65989.5 BILLION BTU	53354.0 BILLION BTU
EXPENDITURES	$ 0.0 THOUSAND	$ 0.0 THOUSAND	$ 0.0 THOUSAND

YEAR	1974	1971	1967
USAGE	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.	ALL FUNCTIONS-TOT.
USER	CAR-PRIVATE	CAR-PRIVATE	CAR-PRIVATE
CONSUMPTION	71329.6 BILLION BTU	65989.5 BILLION BTU	53354.0 BILLION BTU
EXPENDITURES	$ 0.0 THOUSAND	$ 0.0 THOUSAND	$ 0.0 THOUSAND

Appendix G

POLLUTION CONTROL EQUIPMENT

POLLUTION CONTROL EQUIPMENT*

Cyclone Collectors

The simplest and most widely used mechanical collector used on wood-fired combustion systems is the cyclone collector, illustrated in Figure G-1. This device has been used for many years on boilers that burn coal or wood and, until air pollution regulations became more stringent, was the only collection equipment used on many installations. As can be seen in the figure, the dirty gas, laden with particles, enters at the top of the cyclone tangentially and swirls down the length of the device. The air then changes direction and rotates up the center of the cyclone and out the exhaust port. The rotary action of the gas stream throws the particulate matter out to the walls of the cyclone where it impinges and falls down to the collection hopper on the bottom. This hopper is emptied periodically as required.

The collection efficiency of a cyclone varies greatly depending on the size of the particles being collected and how the unit is operated. More than 90% of large particles can be collected with a cyclone, but most smaller particles tend to pass right through the device. Control of air flow is the most important factor in cyclone performance. If air flow is too low, the swirling action and inertial separation does not take place. If air flow is too high, the collected particulate may be re-entrained and passed through the cyclone exit.

The chief advantages of the cyclone include low maintenance and relatively low first cost. Cyclones are often used as the first stage of gas cleaning and may be installed in series with another collection device.

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*Source: Bulpitt, William S., et al, "A Feasibility Study for Wood in Georgia," Georgia Tech EES Project A-2140, sponsored by Coastal Plains Regional Commission, 1979

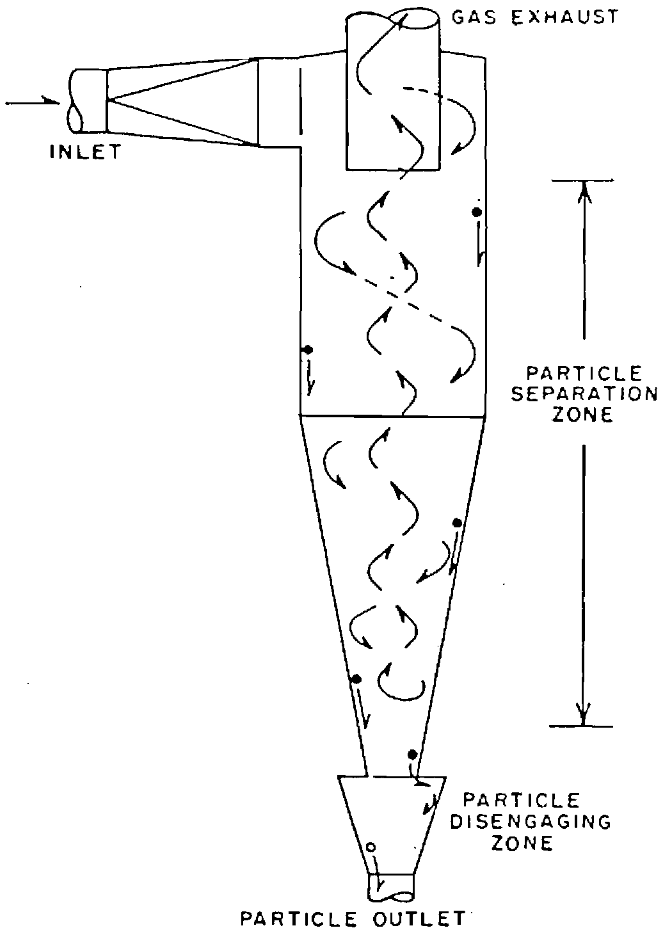


Figure G-1

CYCLONE COLLECTOR

Multiple Cyclone Collectors

A typical multiple cyclone, or multiclone collector, is shown in Figure G-2. This type of collector is merely a grouping of small cyclones that break up a large air flow and pass it through many small units, thereby increasing the effectiveness of the inertial separation. Efficiency of these units may exceed 98%, again depending on the particle size of interest. These systems are more expensive than single cyclones, but are still relatively inexpensive.

Dry Scubbers

Several companies have developed dry scrubbing systems in the past several years that have been quite effective in dealing with wood boiler emissions. An illustration of one such system is shown in Figure G-3 . The basic principle of operation is quite simple. The filtration medium is small rocks constantly recirculated through the system. The particulate-laden gas is routed through the rock bed where the particles impinge on the rocks and are thus collected, allowing the clean gas to pass through the collector to the stack. The rocks are then cleaned by a vibrating system, and the collected ash is removed. The rocks are then recirculated to collect more particulate.

The manufacturer of one of these systems claims a collection efficiency in excess of 99%. Most applications for this type of technology will be large boilers, and the first cost can be expected to be high. However, energy requirements appear to be modest, so operating costs will be lower than higher energy systems.

Wet Scrubbers

As air quality regulations have become more stringent, wet scrubbers have been used for cleanup of many new wood boilers and, in fact, have been retrofitted to many existing

Figure G-2

MULTIPLE CYCLONE COLLECTOR
(Courtesy Zurn Industries Inc.)

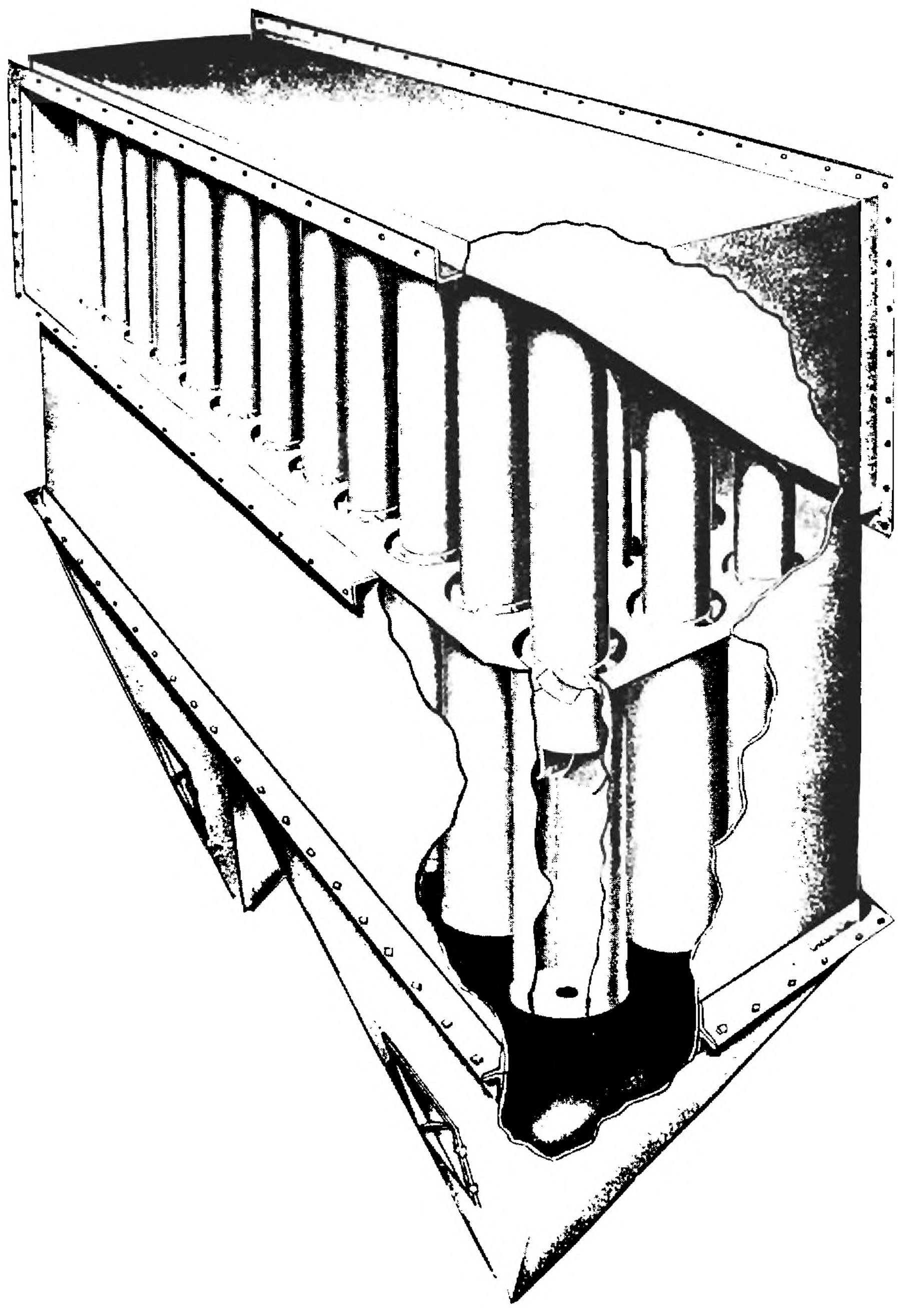
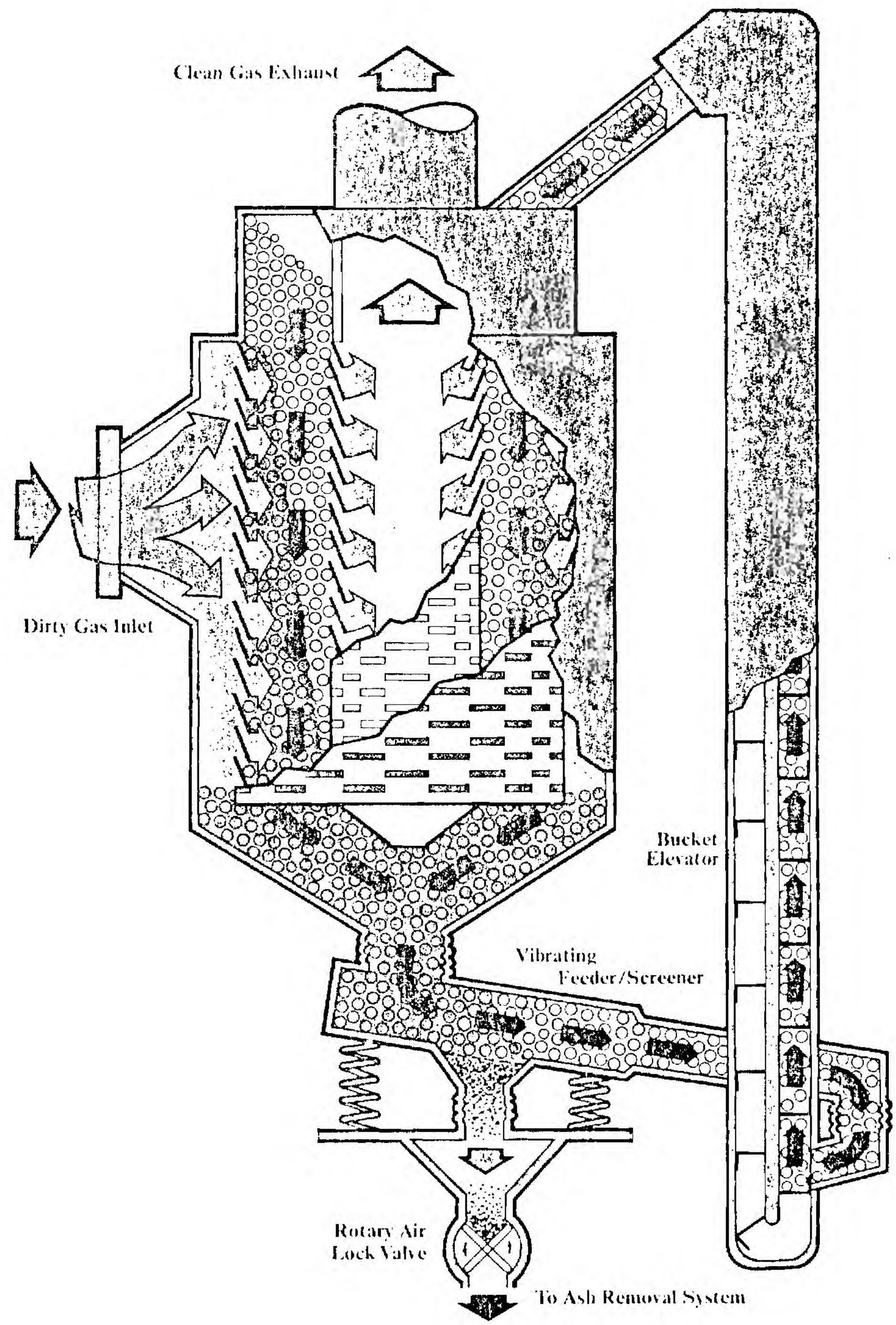


Figure G-3

SCRUBBER
(Courtesy of Combustion Power Inc.)



large wood and bark boilers in the Southeast. An illustration of a typical venturi-type wet scrubber is shown in Figure G-4.

Most wet scrubbers employ venturis for accelerating the flue gas. A water spray is introduced into the venturi and the fine particles are captured by the water droplets. The water is then separated from the cleaned gas in an inertial separator, and the particulate-laden water is removed as a slurry. This slurry can be circulated to a settling pond or disposed of in some other manner. The amount of turbulence introduced in the venturi has a direct effect on the ability of the water spray to collect particulate. In general, the higher the pressure drop across the venturi, the higher the efficiency of the scrubber. Higher pressure drops require bigger and more powerful fans for moving the flue gas, and it is in this regard that wet scrubbers become expensive to operate. They generally require a great deal of energy to keep the gas moving, and thus annual costs become high relative to other types of collectors. Collection efficiencies are also very high, however, and approach 100% for the particulates of interest to the wood burner.

Electrostatic Precipitators

Electrostatic precipitators have been used for many years for the control of particulate emissions, but most applications of this technology have occurred with coal-fired boilers. Precipitators have also been used extensively with paper mill recovery boilers.

A typical electrostatic precipitator is shown in Figure G-5 . A precipitator ionizes particles as they enter the device, and these particles are then attracted to collection plates which are oppositely charged. These plates are cleaned periodically by "rapping" them mechanically, and the collected particulate falls down into

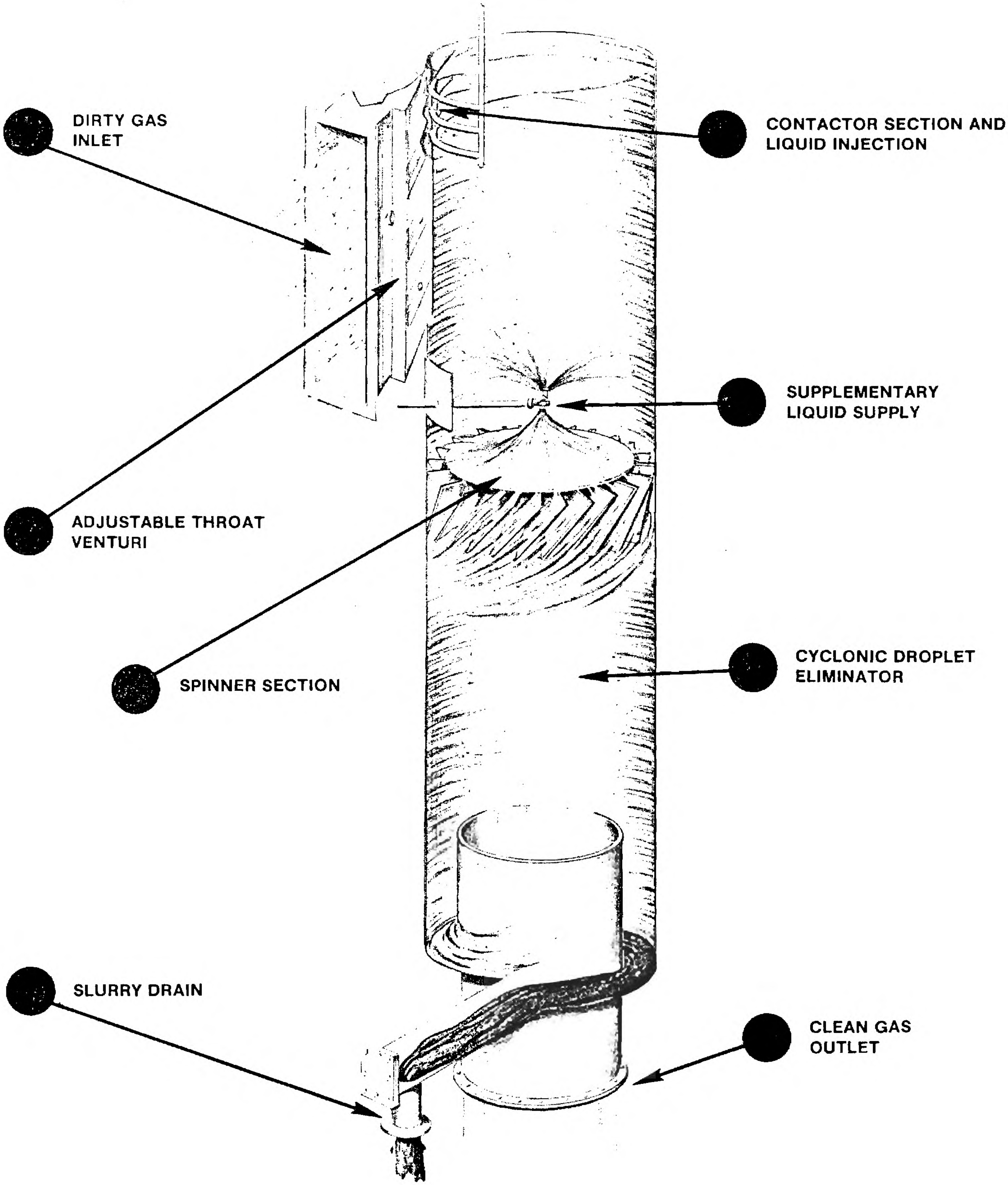


Figure G-4

VENTURI WET SCRUBBER
(Courtesy Fisher-Klosterman Inc.)

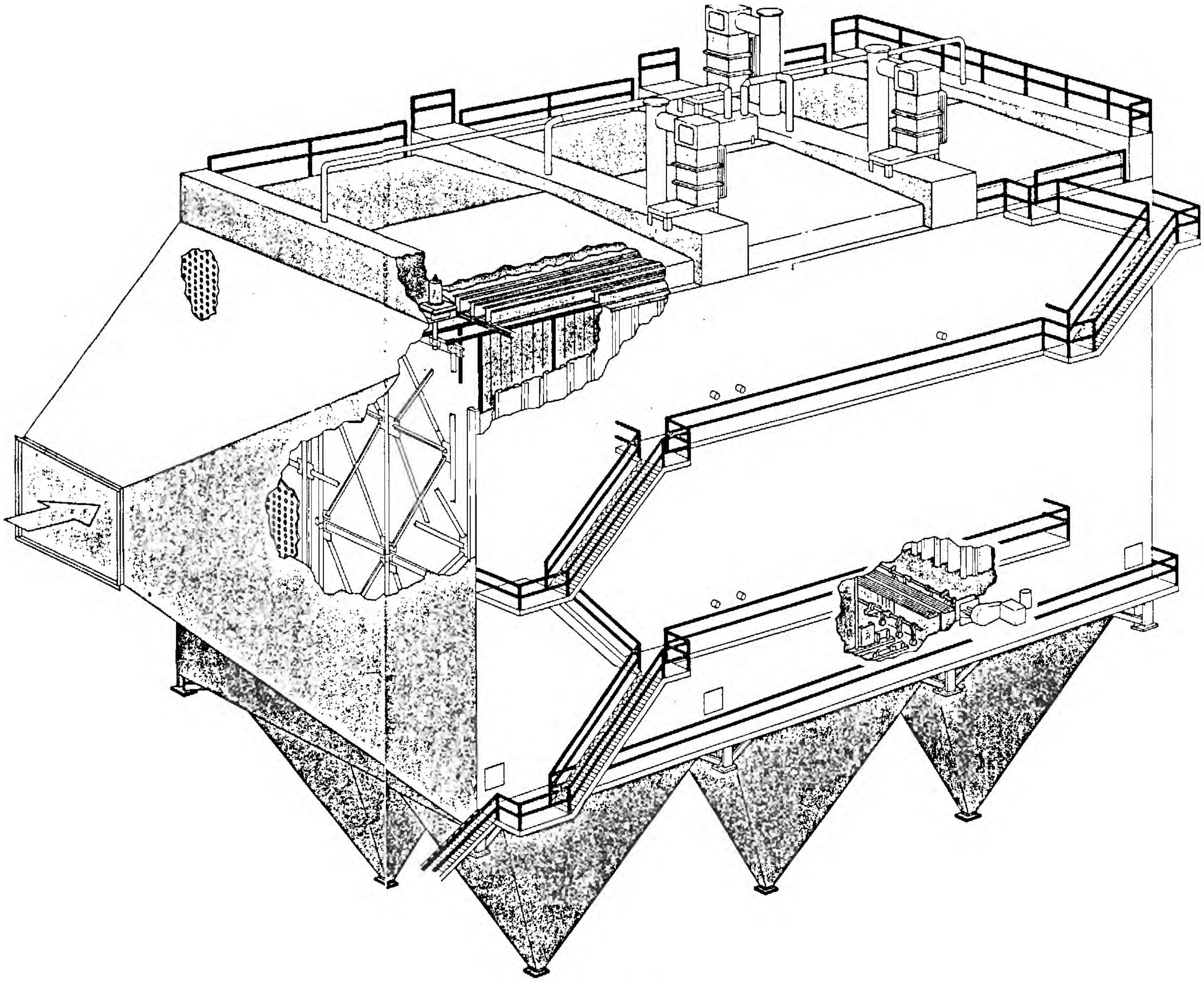


Figure G-5

LARGE ELECTROSTATIC PRECIPITATOR
(Courtesy C-E Walther Inc.)

ash hoppers where it is removed. Electrostatic precipitators are generally quite large physically and are relatively expensive to install. They do, of course, consume electricity, which contributes substantially to operating expense, and maintenance of internals can be costly.

Collection efficiency of electrostatic precipitators depends greatly on resistivity of particulates to be collected, and precipitator performance is relatively poor when particles are extremely high or low in resistivity. Wood particles apparently are low in resistivity and may not be effectively collected by precipitators when wood is the only fuel being burned. However, when coal is being burned as well as wood, the overall performance of the precipitator on the combined wood and coal particulate may be satisfactory. Thus these units will be of interest in those installations being built to handle both types of solid fuel.

As with most other types of collectors, precipitators are usually preceded by a first stage of mechanical cleaning (such as a cyclone) to lessen the total load on the precipitator.

Baghouses

The last type of pollution control device to be considered here is the fabric filter system or baghouse. For wood-fired boilers and combustion systems, applications of baghouses are quite controversial since potential operators are very concerned with the possibility of fire. The EPA, however, considers the baghouse to be the technology achieving the lowest achievable emission rate (LAER) for wood-fired boilers. It is generally true that fabric filter systems are highly efficient for particle collection, even down to very small particle sizes.

A typical baghouse installation is illustrated in Figure G-6. The methods of collection vary, but normally the baghouse consists of a large number of cylindrical bags made of fiberglass, nomex, or other material (depending on flue gas temperature) through which the flue gas passes. Particles are collected on the inside or outside of the bags (depending on the particular system configuration), and the bags are periodically cleaned by isolating zones from the flue gas stream and mechanically shaking, reverse air flowing, or air blasting the bags. This action results in the particulate falling to the bottom of the housing into an ash hopper.

Regardless of material, any type of bag will have a temperature limitation, and if a glowing ember from a wood fire should enter a baghouse and start a fire in the collected ash, a great deal of damage to the baghouse can result. It is for this reason that many wood boiler operators are hesitant to adopt this technology, although certain installations have been operated successfully with wood fuel.

Baghouses are not as energy intensive as other scrubber systems since pressure drops are lower; but periodic replacement of the bags is necessary even under normal operation, and this can be an expensive proposition. Normal bag life is 18 months or less. If fossil fuels containing sulfur are fired in the combustion system, the sulfur-bearing compounds can cause corrosion of the bags and supporting structures. This can be adequately controlled by choosing the proper bag material and operating the unit under proper temperature conditions. Baghouses approach 100% collection efficiency and will probably realize further applications on wood-burning sources in the future.

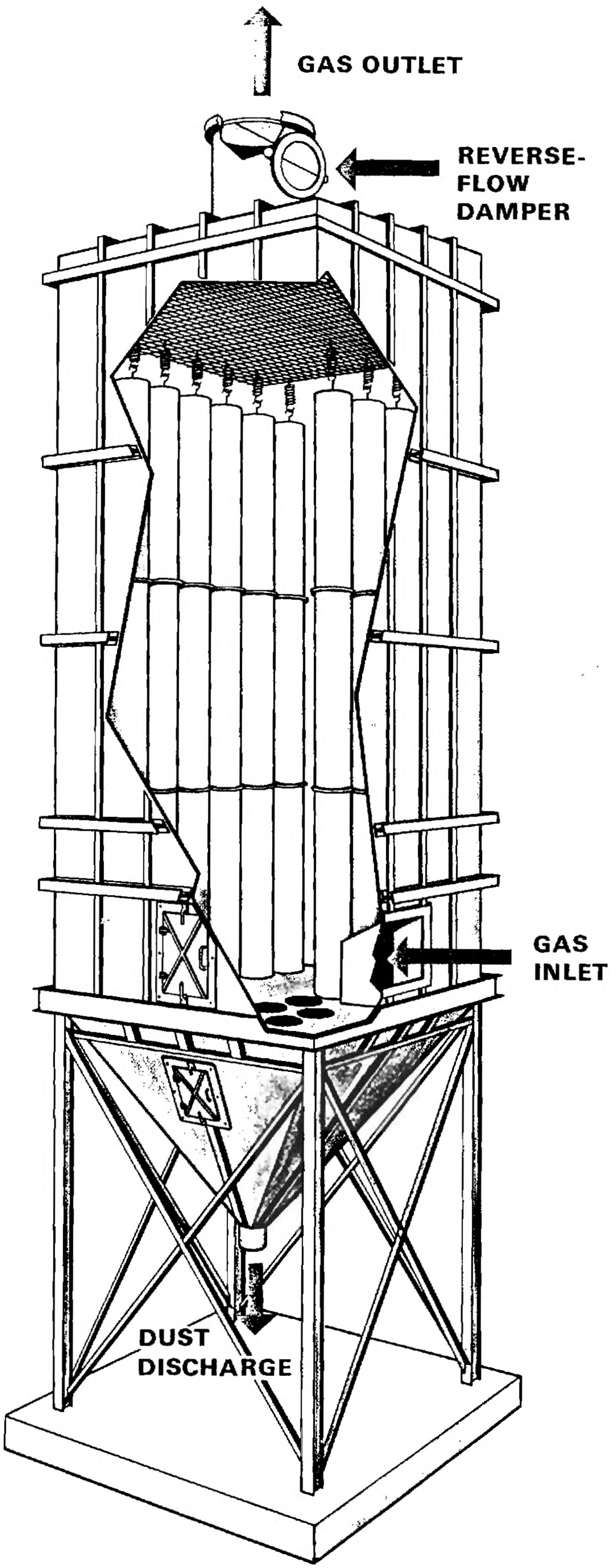


Figure G-6

A BAGHOUSE
(Courtesy Zurn Industries Inc.)

Relative System Efficiencies

It is difficult to make sweeping generalities about pollution control device collection efficiencies since their applications will be very site specific in most instances. The most important factors to consider will be dust concentrations, particle sizing, and flue gas temperatures. When deciding on the system for a new installation, the specifying engineer would do well to review similar applications of the devices being considered to assess their relative performance.

Table G-1 presents some relative data on collection device performance collected for the EPA. These data could be used as a starting point for the choice of a collection system, after the particle size distribution of the source has been determined.

Relative System Costs

As mentioned previously, the desire of most industrial plants will be to comply with relevant air pollution regulations at minimum cost. There is little to be gained from overcorrecting the situation. Thus, it may often be the case that several types of collection systems will achieve the desired result, and the final choice will be decided on relative costs of the systems.

Again, it is very difficult to try to generalize overall costs for a particular combustion source based on limited information, but some information on relative costs of various systems has been collected (mostly from equipment vendors), and this information will be presented here.

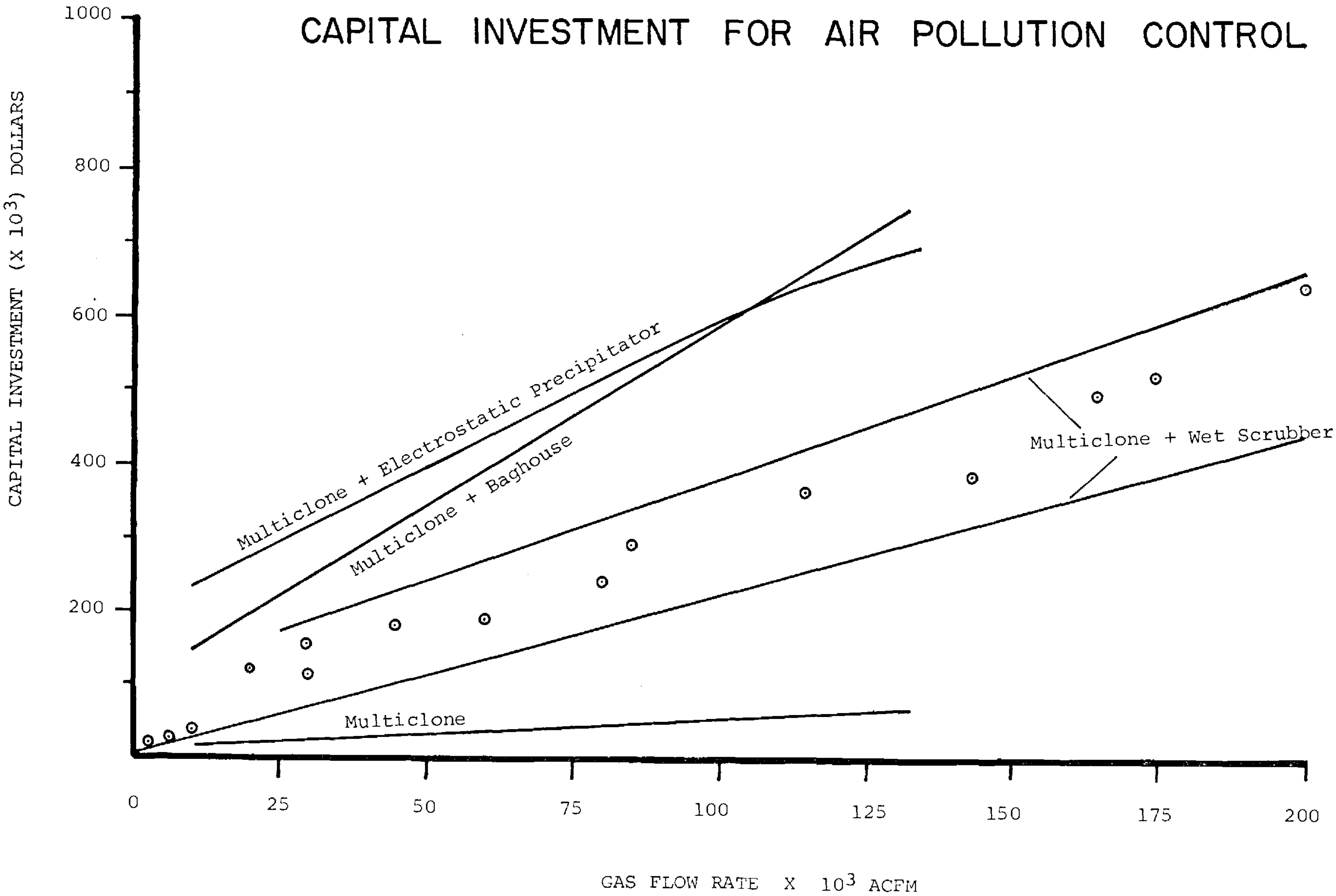
Figure G-7 presents some cost curves for several types of air pollution control systems. The lowest curve gives the installed cost for a multiclone mechanical collection system. The next highest cost range is for multiclones followed by

Table G-1

RELATIVE COLLECTION EFFICIENCIES
OF VARIOUS POLLUTION CONTROL DEVICES

	Collection Efficiency %					
	Particle Size Range, Microns					
Type Collector	Overall	0-5	5-10	10-20	20-44	>44
Simple Cyclone	65.3	12.0	33.0	57	82.0	91
Multiple Cyclone (12 in. dia.)	74.2	25.0	54.0	74	95.0	98
Multiple Cyclone (6 in. dia.)	93.8	63.0	95.0	98	99.5	100
Electrostatic Precipitator	97.0	72.0	94.5	97	99.5	100
Venturi Scrubber	99.5	99.0	99.5	100	100.0	100
Baghouse	99.7	99.5	100.0	100	100.0	100

Figure G-7



CAPITAL INVESTMENT FOR AIR POLLUTION CONTROL
1000
800
600
400
200
CAPITAL INVESTMENT (X 10^3) DOLLARS
Multiclone + Electrostatic Precipitator
Multiclone + Baghouse
Multiclone + Wet Scrubber
Multiclone
0
25
50
75
100
125
150
175
200
GAS FLOW RATE X 10^3 ACFM

medium energy wet scrubbers, and the upper curves give cost comparisons for electrostatic precipitators and baghouses. It easily can be seen that precipitators and baghouses will probably be used only as a last resort due to the high first cost. Of course, operating costs must be considered as well, and these are estimated in Figure G-8. In this graph, the high costs of electric fans and water becomes apparent for wet scrubber operation. Annual cost for baghouses is also quite high when the bag replacement costs are considered. Precipitator operating costs are relatively lower, but are highly dependent on costs for electricity and, as expected, the annual costs for multiclone operation are quite low.

Some data for large systems are included here as indicated by the steam flows on the lower scale but, for moderate size industrial plants, the largest gas flow of interest probably will be about 70,000 acfm, roughly corresponding to a 100,000 lb/hr boiler. It easily can be seen that the cost of emission control can contribute a large expense to an overall system cost.

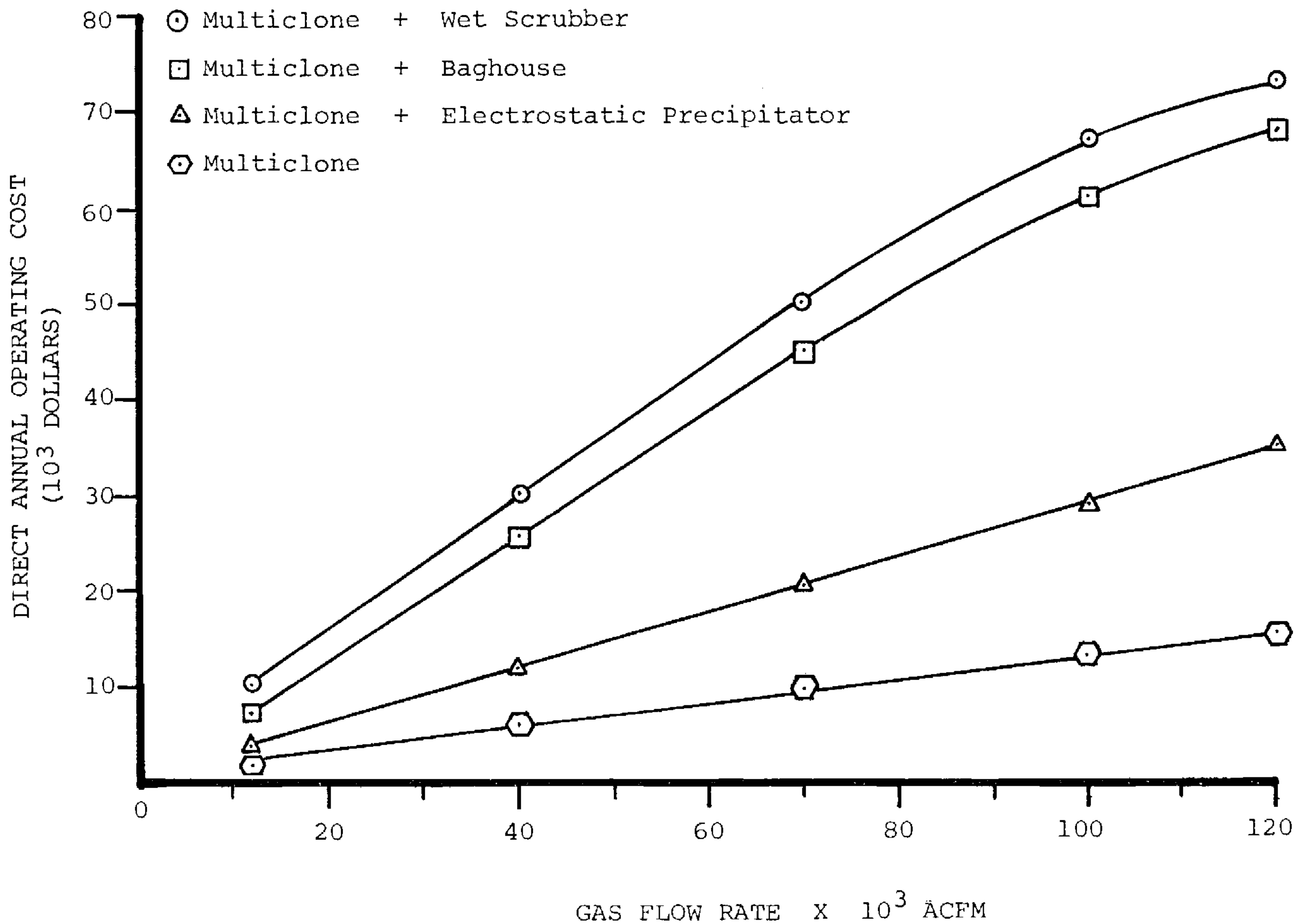
Ash Removal and Disposal

Relative to coal, wood contains a small amount of ash, usually 1% to 3%. Wood residue and harvested chips can contain additional quantities of sand and other foreign matter that can be carried through the boiler to be collected in various settling chambers, hoppers, and pollution control systems. This material can create a solid waste disposal problem, but not as bad a problem as coal ash disposal.

Many package boilers and smaller combustors require manual de-ashing, and this is typically done by the boiler operator once during his shift. Larger units, as we have seen, may incorporate elaborate automatic ash removal systems such as traveling grates or reciprocating grates. These devices often dump ashes automatically into receiving

Figure G-8

OPERATING COSTS OF AIR POLLUTION CONTROL SYSTEMS



bins which are emptied periodically. Most of the boiler operators that were contacted during the course of a separate study at Georgia Tech did not consider wood ash disposal to be a major problem. Some larger scrubber systems may require settling ponds which must be cleaned out periodically, but most plants merely dispose of wood ash in municipal landfills or use it as fertilizer.